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Research activities of STUK 2005–2010

S. Salomaa, N. Sulonen (Eds.)

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Strålsäkerhetscentralen
Radiation and Nuclear Safety Authority

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Key words: research, radiation protection, evaluation, ionising radiation, non-ionising radiation

Abstract

The primary goal of STUK, the Finnish Radiation and Nuclear Safety Authority, is to protect people, society, the environment and future generations from the harmful effects of radiation. The research conducted by STUK yields new information related to the use, occurrence and effects of radiation. The present report summarises STUK's own research activities related to radiation protection in 2005–2010. The research and its organisation, scientific strategy and priorities, the impact of results, publications, and the functions of research laboratories are all reviewed. This report has been written to provide background material for an international evaluation of STUK research carried out in autumn 2011. A follow-up of actions taken after the first international research evaluation mission in 2005 will be provided. An overview is presented of the on-going structural renewal of the national research system and its impact on STUK.

SALOMAA Sisko, SULONEN Nina (toim.). Säteilyturvakeskuksen tutkimustoiminta 2005–2010. STUK-A248. Helsinki 2011, 273 s.

Avainsanat: tutkimus, säteilysuojelu, toiminnan arviointi, ionisoiva säteily, ei-ionisoiva säteily

Tiivistelmä

Säteilyturvakeskuksen (STUK) päämääränä on suojella ihmisiä, yhteiskuntaa, ympäristöä ja tulevia sukupolvia säteilyn haitallisilta vaikutuksilta. Säteilyturvakeskuksen tutkimustoiminta tuottaa säteilyn käyttöön, esiintymiseen ja vaikutuksiin liittyvää uutta tietoa. Tämä raportti on yhteenveto STUKin säteilysuojelututkimuksesta vuosina 2005–2010. Raportissa käydään läpi tutkimustoiminta ja sen organisointi, tieteellinen strategia ja painopistealueet, tulosten vaikuttavuus, julkaisutoiminta ja tutkimusyksiköiden toiminta. Yhteenveto toimii taustamateriaalina STUKin tutkimuksen kansainväliselle arvioinnille, joka tehdään syksyn 2011 aikana. Raportissa kuvataan myös edellisen, vuonna 2005 suoritetun tutkimuksen kansainvälisen arvioinnin suositusten pohjalta tehdyt toimenpiteet ja kerrotaan kansallisen tutkimuslaitosjärjestelmän uudistamisen vaikutuksista STUKin osalta.

Contents

Introduction

The Radiation and Nuclear Safety Authority (STUK) is a regulatory authority, research institution and expert organisation, whose mission is to protect people, society, the environment and future generations from the harmful effects of radiation. The ultimate objective is to keep the radiation exposure of Finnish citizens 'as low as reasonably achievable' (the ALARA principle) and to prevent radiation and nuclear accidents with a very high degree of certainty (Safety As High As Reasonably Achievable or the SAHARA principle). The confidence of the general public and stakeholders' views on the significance of STUK's operations in enhancing safety are also key indicators of the quality of its work.

One key objective of STUK research is to extend professional knowledge that supports regulatory operations and the maintenance of emergency preparedness. The quality of the research carried out is under continuous self-assessment, and internal procedures have been established to promote continuous improvement. Peer review of scientific articles in international journals is used as an external quality measure and independent reviews on the effectiveness and quality of research are carried out every five years. The evaluation of research activities at STUK aims to address the following main issues: the appropriateness of STUK's activities in relation to relevant issues in radiation protection, the social relevance and effectiveness of its activities, steering by information, the prioritisation of STUK's various activities, the quality of STUK's research activities, and the relationship between costs and results. This is now the third time that STUK's entire research activities are being subjected to external review by international radiation protection experts and scientists.

During the evaluation period and beyond, declining resources for research both nationally and internationally have posed new challenges to STUK and the scientific community in radiation research. At the same time, new policy questions and paradigms have arisen that require multidisciplinary research efforts and the pooling of resources not only on the national, but also the European and international levels.

1 Brief history of STUK as a research organisation

The Institute of Radiation Physics, the predecessor of the Radiation and Nuclear Safety Authority (STUK), was founded as a research institute in 1958. Its functions had been defined earlier, in 1957, in the Radiation Protection Decree. They were primarily to monitor the safety of X-ray equipment and other radiation sources used in hospitals, to carry out the necessary radiation measurements related to radiation therapy, and to study the consequences of atmospheric nuclear tests for human health and the environment.

In the early years, STUK research focused on developing radiation metrology and personal dosimetry, and on radioecological studies in the environment. Wider use of radiation in medicine and industry in the early 1960s forced STUK to develop more accurate methods for calibrating X-ray and radiation therapy machines, and also to develop its own dosimetry system for personal dose control. On the other hand, atmospheric nuclear tests in the 1950s and early 1960s generated public pressure for research on exposure of the population to radioactive fallout and how the various radionuclides behave in the Finnish environment. These radioecological studies also led to the establishment of a separate laboratory in northern Finland to study more closely the behaviour of radionuclides in sub-Arctic food chains. The laboratory was founded in 1970 in Rovaniemi.

The first investigations on the exposure of underground miners to high concentrations of radon and its progeny were performed in the 1970s. These studies led to regular monitoring of workers' exposure and the introduction of guidelines for action levels, monitoring frequencies and mitigation measures. The first findings on exceptionally high levels of natural radionuclides in groundwater also date from the late 1960s.

In the 1970s, after a political decision had been made to build a nuclear energy capacity in Finland, STUK's resources were increased by giving it greater research capabilities. The main research areas in this period were the behaviour of radionuclides in the environment and their transfer to the human body, the occurrence of radon and other natural radionuclides in underground and surface waters and in building materials, radon in houses and workplaces, and the development of new methods for radiation surveillance in the immediate surroundings of future nuclear power plants. The first experimental studies on radiobiology and non-ionising radiation were also carried out.

The nuclear accident at Chernobyl in 1986 had significant radiological consequences in Finland. The radioactive fallout necessitated extensive investigations on public exposure to the released radionuclides, the occurrence and behaviour of radionuclides in the environment, and on effects on the health of exposed people. The needs for experimental radiobiological research, for the use of modern biological dosimetry and for epidemiological studies increased. More effort was put into developing emergency preparedness tools, including automatic monitoring networks, environmental modelling and decision-aiding techniques. Research became more networked with domestic and foreign research institutes and the number of joint projects increased.

STUK co-operates closely with the other Nordic countries in radiation protection research. This co-operation started even before the official establishment of STUK, that is, in 1957, when the Nordic Liaison Committee for Nuclear Energy Questions (NKA) was set up. Nordic research co-operation advanced to a new phase in 1975, when a new co-operation forum, Nordic Nuclear Safety Research (NKS), was established. This co-operation takes place within four-year framework programmes.

The collaboration with the New Independent States of the former Soviet Union and Eastern European Countries increased considerably in the 1990s, especially in nuclear safety but also in research related to the environmental and health effects of the Chernobyl accident and the former nuclear tests. The establishment of the National Data Centre related to the Comprehensive Nuclear Test Ban Treaty also promoted new research functions in the late 1990s. In 1995, Finland joined the European Union and, ever since, STUK has played an active part in the research programmes of the European Union. The expansion of STUK functions is illustrated in Figure 1.

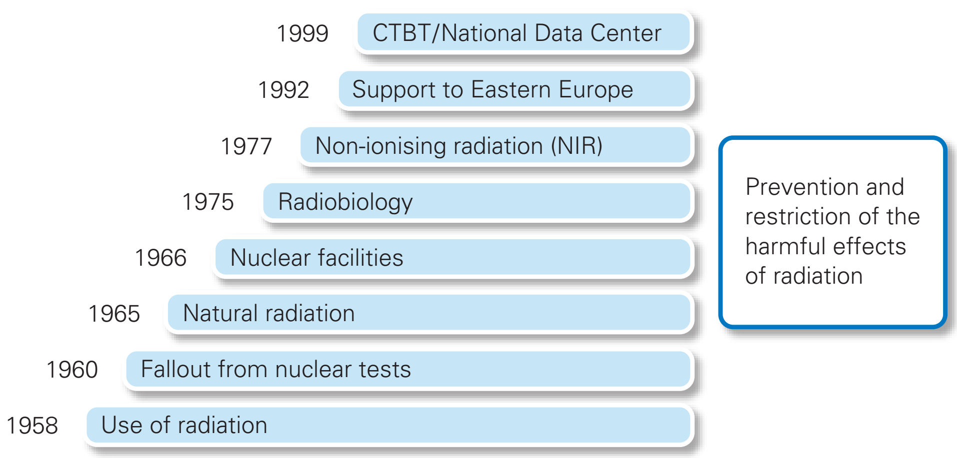


Figure 1. Expansion of the functions of STUK.

2 Research strategy and action plan

The Radiation and Nuclear Safety Authority (STUK) is a regulatory authority, research institution and expert organisation, whose mission is to protect people, society, environment, and future generations from the harmful effects of radiation. The ultimate objective is to keep the radiation exposure of Finnish citizens 'as low as reasonably achievable' (the ALARA principle) and to prevent radiation and nuclear accidents with a very high certainty (Safety As High As Reasonably Achievable or the SAHARA principle). The confidence of the general public and stakeholders' views on the significance of STUK's operations in enhancing safety are also key indicators of the quality of its work.

The evaluation of STUK research activities aims to address the following main issues: the appropriateness of STUK's activities in relation to relevant issues in radiation protection, the social relevance and effectiveness of activities, steering by information, prioritising STUK's various activities, the quality of STUK's research activities, and the relation between costs and results. The research carried out at STUK is related to radiation protection, covering both ionising and non-ionising radiation. In addition, STUK experts also supervise nuclear safety research projects (safe use of nuclear power and nuclear waste management) commissioned by the authorities and conducted by organisations outside STUK. However, the present review only covers the strategy, organisation and results of radiation protection research carried out by STUK itself.

2.1 Aims for research and research areas of STUK

The two main goals of STUK research are to provide new knowledge on scientific questions related to the system of radiation protection and to extend professional competence that supports regulatory operations and the maintenance of emergency preparedness. The quality of the research is under continuous self-assessment, and internal procedures have been set up to promote continuous improvement. Peer review of scientific articles in international journals is used as an external quality measure and independent reviews on the effectiveness and quality of research are carried out every five years. This is now the third time that all STUK's research activities are being subjected to external review by international radiation protection experts and scientists.

The research areas of STUK are:

- Health effects of radiation
- Use of radiation
- Occurrence and mitigation of natural radiation

- Environmental research
- Preparedness for radiological threats and emergencies
- Dosimetry and metrology
- Non-ionising radiation
- Nuclear safety
- International and national collaboration

Research on the health effects of radiation (ionising and non-ionising) is the largest research area, followed by preparedness for nuclear and radiological threats and emergencies and environmental research. For more details on resources, see chapter 3.

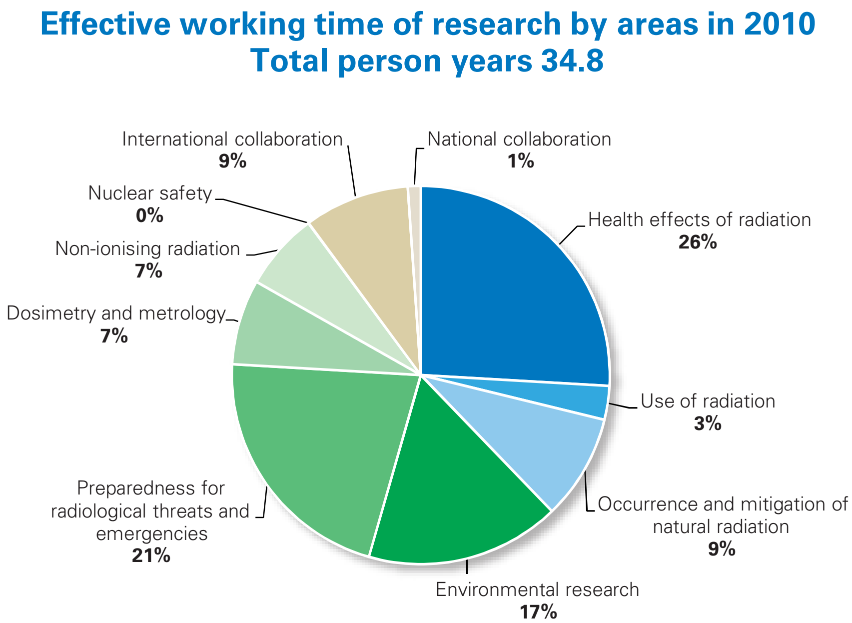


Figure 2. Effective working time in different research areas in 2010.

2.2 Research process and STUK quality guidance

STUK's quality system is based on international quality standards (ISO 9004: Quality management systems – Guidelines for performance improvements, and ISO/IEC 17025: General requirements for the competence of testing and calibration laboratories). In addition, the requirements presented in IAEA Safety Standards are applied in authority work (GS-R-3: The management system for facilities and activities). The principles of total quality management (the EFQM Excellence Model), are also applied.

The quality policy of STUK – "This is how we operate – quality policy of STUK" is the principal document directing the quality system. The rest of the quality system is specified by other guides and orders of the STUK Quality Manual. The STUK Quality Manual is complemented by other STUK-level manuals as well as quality manuals and guides that are valid in different fields of STUK's activities. All the guides and plans are available on the Intranet.

In 1999 the quality policy of STUK was extensively defined and the latest update was made in 2008. The management of STUK is committed to observing the quality system and to continuously improving the quality of activities. Customer focus is an essential part of the quality of work.

2.2.1 Guidance of research process

Research is one of the core processes of STUK. Guidance on the conduct of research in STUK is provided in STUK Guide 3.2. The Guide provides a description of the scope of research to be conducted at STUK, the responsibilities and the procedures to be followed when planning, carrying out and reporting the results of research projects.

The proposals for new projects are evaluated by the Research Director and directors of the departments involved in the implementation. All research projects must be in line with STUK strategy. The research plan describes the project objectives, execution, resources needed, expected outcomes and dissemination of results. The plan also indicates how, where and how long the samples, measurement data and files are to be stored. A separate dissemination plan is requested for all major projects with strategic impact. The proposed research projects are evaluated and scored according to their relevance, the need for new knowledge, improvement in competence, scientific quality and potential impact. Ranking of the projects is used when the department directors decide which projects are to be included in the annual programme, depending on the resources available.

STUK Guide 3.2 also provides guidance on project meetings, documentation on materials and follow-up of progress. Up-to-date equipment and software are used for research and infrastructures are planned and developed on a long-term basis. Results are published in international journals or report series of STUK and other research institutes. The publication forum is decided on the basis of the target audience and end-users of the results. A lay-man summary of international publications is prepared for use by the Information Unit. The productiveness of research is evaluated in terms of the number and quality of publications. In addition to scientific publications, other outputs and benefits are derived from research, such as software and equipment or guidance and recommendations to a variety of stakeholders. The execution and outcomes of each research project are evaluated by the Research Director or experts nominated by her/him within three years of the end of the project.

Research ethical guidance includes national guidance on good scientific practise, intellectual property rights for publications and principles for approving and administering external funding, as well as the overall independence of science and interpretation of research results. The Research Ethics Group was established in 2008 to follow the overall development of ethical guidance in Finland and to consult on the need for ethical approvals by relevant bodies. The areas of research that need particular attention deal with human material and/or personal identification information. The Group also arranges training on a frequent basis. Ethical approval for projects is requested from independent bodies outside STUK.

2.2.2 Accredited processes

Accreditation of laboratory processes was awarded by FINAS (the Finnish Accreditation Service) in 1999 and was renewed in 2003, 2007 and 2011 according to European Standard EN ISO/IEC 17025. The accreditation field is "Test of radiation safety and related environmental sampling" (Test laboratory T167). Separate accreditation fields are:

- Advanced gamma spectrometric analyses (all gamma nuclides)
- Gamma spectrometric measurements (Cs, I, K, U, and Th isotopes)
- Radiochemical analyses (tritium, isotopes of Sr, Pu, Am, Cm, Rn, Po, Pb and U)
- Direct measurement of people
- Airborne radon concentrations
- Chromosome analyses
- Sampling for control of radioactivity
- Method for local laboratories, NaI(Tl) detector

Since the accreditation was adopted, external audits by FINAS have been performed annually. In addition, internal audits of each separate accredited field have been carried out in order to ensure continuous development of the laboratory processes.

The laboratory has also been certified by the Comprehensive Test Ban Treaty Organization (CTBTO). Most of the requirements are based on standard ISO/IEC 17025. Some additional requirements are set for the safety of samples, the measurement system and analysis of data. The CTBT laboratory work is evaluated regularly by the CTBTO.

2.2.3 National Metrology under Mutual Recognition Arrangement, CIPM MRA

In 1999, Finland signed an international agreement on national metrology (Mutual Recognition Arrangement, CIPM MRA) established by the International Committee for Weights and Measures (CIPM). According to the agreement, participants recognise each other's national measurement standards and calibration and measurement certificates issued by the National Metrology Laboratories (NMLs). The MRA presumes that the standard ISO/IEC 17025 is fully implemented and followed by the NMLs. In Europe, the fulfillment of the agreement is coordinated by the European Association of National Metrology Institutes (EURAMET). The implementation and development of the quality system is reported annually to the EURAMET technical committee for quality. Every five years the quality system of NMLs is described by each signatory country and is evaluated by the EURAMET technical committee for quality. So far, the quality system for national metrology of STUK has been evaluated and accepted twice, i.e. in 2003 and 2009. External audits have also been performed for the national metrology of STUK. Currently, the activities under CIPM MRA cover the metrology and calibration capabilities for dosimetry, i.e. for measurement quantities of ionising radiation based on air kerma and absorbed dose to water. For national metrology activities the principle of self-declaration is applied instead of third party accreditation.

2.3 Arrangements for setting and modifying the research strategy

The mission of STUK is to protect people, society, the environment, and future generations from the harmful effects of radiation. Besides a research centre, STUK is also a regulator and inspectorate. In addition, STUK has the role of an emergency preparedness organisation in nuclear and radiation hazard situations. STUK is a national laboratory responsible for the maintenance of national standards for radiation metrology. STUK also provides expert services in the surveillance of environmental radioactivity and metrology. STUK's areas of operation cover the whole range of radiation and nuclear safety and ionising and non-ionising radiation.

STUK has one strategic plan that is updated every fifth year. The current strategy encompasses the period from 2007–2011. The strategy describes the mission, vision, success factors, values, operational environment, focus areas (effectiveness, processes and structures, development and functional capability, resources and financing), topics elaborated further in specific action plans and performance indicators. The STUK-level strategy is complemented by action plans prepared for all core processes, including research.

The process approach promoted by standard ISO 9001:2000 was adopted in 2002. Extensive work has been done since then, first by identifying and describing the main processes and then updating the respective manuals, and preparing flow charts. The work with the processes has continued for several years. There now exists, among other resources, a table for core processes and support processes identifying outcomes of the respective process, the process monitor, process owner and respective quality manual.

Implementation of the strategy takes place via action plans prepared for core processes. In addition to research, STUK has prepared action plans for: the regulation of nuclear power plants, nuclear materials and nuclear waste, and radiation safety – ionising radiation, regulation of radiation safety – as well as non-ionising radiation, metrology, surveillance of environmental radioactivity, preparedness for emergencies, information and data management, public communication and rule making.

The vision of STUK is:

- The level of radiation safety and nuclear safety is high in Finland, and provides an outstanding standard for international benchmarking.
- STUK is well known and respected as an expert organisation and research centre, as an independent regulator dedicated to safety, and as an influential national and international actor.

Carrying out the STUK strategy, the success factors are:

- Our impact on the maintenance and development of radiation and nuclear safety is effective and risk informed.
- Our safety regulations are in line with good international practice.
- Our research is of high quality and focused on the key issues of radiation protection.
- Our work processes are consistent, cost-effective and well-defined.
- The availability, quality, and timeliness of our services meet the expectations of our clients and partners.
- The quality and effectiveness of our work are continuously and systematically improved.
- Our personnel are in good mental and physical condition.
- Our personnel are professionally competent, highly motivated, and have a high work ethic.
- Our financial situation, working conditions and tools are good.

Basic values that direct STUK's operations are competence, co-operation, openness and courage. According to these, decisions, positions and other measures are based on professional knowledge, research and competence; co-operation within STUK is based on good partnership, participation and mutual respect and stakeholders are involved in the planning of actions; action is open and honest, both towards stakeholders as well as in internal communication; problems are identified, as well as personal views, and followed up rigorously. Responsibility for individual decisions and actions is acknowledged and possible errors are corrected.

The strategy of STUK has been formulated according to the Balanced Scorecard (BSC), which covers the goals for effectiveness, the processes and structures, regeneration, working capacity and resources and financing (see Fig. 3). The focus areas are set according to the main processes.

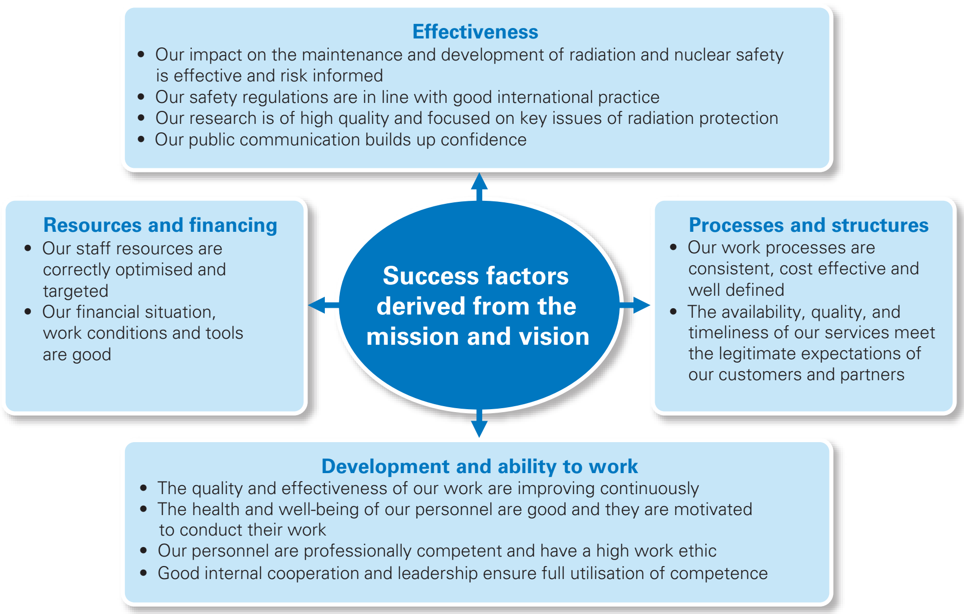


Figure 3. Success factors derived from the mission and vision.

2.4 Changes in the operational environment

Upon the updating of the STUK strategy in 2006–2007, a number of national and international trends and changes were identified that could in one way or another affect the different activities of STUK. Many of them also impact on research either directly or indirectly, affecting the topics taken up or pointing out new partnerships. The following challenges and possibilities in the operational environment were recorded:

- Renewal of international radiation protection principles
- EU directives and recommendations on radiation protection
- Development of IAEA nuclear and radiation safety requirements
- Obligations of international agreements and regulations on emergency preparedness
- National co-operation on emergency preparedness
- Development of medical diagnostics and treatment methods based on the use of ionising radiation
- Increasing the number of radiotherapy units
- Changing the business structure within sectors using ionising radiation
- Foreign companies entering the Finnish market in sectors using ionising radiation
- Increased use of equipment that generates electromagnetic fields
- Increasing exposure of the population to non-ionising radiation
- International terrorism
- The long-term storage and disposal of small-scale radioactive waste assigned as a new duty for STUK
- Uranium exploration in Finland
- The evolving role of the EC in nuclear safety
- Changes in the regulation of nuclear materials by IAEA and EU
- Changes in the global nuclear fuel cycle
- Building nuclear energy nationally and internationally
- Multinational development of procedures on nuclear safety supervision
- Enhancing the safety and efficiency of current reactors and the development of new reactor types
- Modernisation of current nuclear power plants
- Building and commissioning of Olkiluoto 3 NPP
- Final disposal of spent fuel
- Changes in the Nuclear Energy Act and ordinances
- 7th Euratom Framework Program and Security program
- Evaluation of the risk paradigm of ionising radiation
- Radon prevention and mitigation
- Improved technologies for nuclide identification
- Increasing international interest on STUK as a collaborative partner
- New arrangements in EU international support on radiation and nuclear safety
- Extension of UNSCEAR

- Enhanced speed of communication globally
- Citizens' demand for more knowledge
- Active non-governmental organisations
- Rapid development of information and communication technologies
- Generation shift among personnel at STUK and other actors in the field
- Recruitment of new employees is becoming more difficult because of the aging population
- Government productiveness programme (more results with less personnel)

In March 2011, the Tohoku earthquake and tsunami led to a major nuclear accident at the Fukushima Da-ichi nuclear power plant in Japan. This event will impact on research worldwide, but the exact consequences remain to be seen at the time of writing this report.

2.5 Identifying priority areas for research

STUK strategy is implemented via action plans that are prepared for each core process, including research. Based on the analysis of changes in the operational environment, the need for new knowledge is identified for the coming years. Areas to be strengthened are discussed in strategy seminars and laboratory meetings. When STUK decides which new projects are prioritised and funded a two-step procedure is followed. First of all, the potential of the research idea is evaluated by considering if it is in line with STUK strategy and if and if STUK has the necessary resources for taking up the project. This initial step is to decide either to proceed with planning or to discard the idea or postpone the implementation (a Go/No-Go step). In case the project idea is approved, a more detailed project plan is provided. The full plan is then evaluated according to the following criteria:

- relevance (is the project in line with STUK strategy and action plan; societal demand; importance for radiation protection; actuality)
- need for new knowledge (repeating old or creating new)
- scientific and technical quality of the plan (competence of research group; quality of the plan; is the plan realistic; cost efficiency)
- impact (chances for prevention, reduction or optimisation of exposure/dose; taking into account the needs of stakeholders; quality of dissemination plan; a new method, procedure or equipment for the use of STUK or stakeholders).

2.6 Dissemination of research results and transfer of knowledge and technology

As part of their self-evaluation seminars and development of procedures, STUK's departments have carried out an analysis of their stakeholders, products and end-users in different areas of action. The products and end-users of STUK research are described in Table I.

Table I. End-users and products of STUK research.

End-user	Product
Decision makers, citizens	Conclusions, recommendations
Scientific community – scientists at research institutes, universities – UNSCEAR, ICRP, BEIR, ICNIRP (risk assessment)	Scientific publications, recommendations for future research
STUK as a regulatory and expert body	Information to support and guide regulation and emergency preparedness, methods, equipment, models
Municipalities, counties	Reports, conclusions, recommendations
Users of radiation	Improved safety procedures
Enterprises	Support for product development
Funding bodies (EC, Finnish Academy of Sciences, NKS, National Technology Agency)	Progress reports, input for research strategy
Individual research units themselves	New methods, improved study protocols, computer models, databases

High-quality scientific publications are the key products of STUK research. They also form a solid basis for the conclusions and recommendations passed on to decision makers and citizens. Publications in peer-reviewed international journals provide the means for communication with the scientific community, including risk assessment organisations. Studies that are of interest mainly at the national or local level are published in a national report series, STUK-A series, in Finnish and/or Swedish. Municipalities and counties are active users of STUK's environmental surveys and databases, such as radon in indoor air or radon or uranium in drinking water.

In addition to publications, new methods, improved study protocols, computer models and databases are products that enhance the capability of STUK to carry out its mission. STUK research also contributes to improved safety procedures that are applied by the users of radiation, for example in medicine. Although STUK carries out quite a lot of technical development, relatively few patents have been registered so far. Over the years, a few spin-off enterprises have been established by former STUK personnel.

2.7 Interaction between research and STUK's work as a regulatory body

Radiation protection research includes research and development that is relevant in protecting people, society, the environment and future generations from the harmful effects of ionising and non-ionising radiation. The radiation protection research carried out at STUK can be broadly classified into applied research deriving from the needs of the authorities and society and as problem-oriented basic research, which typically addresses the health risks of ionising and non-ionising radiation and mechanisms of action of radiation on living cells.

Applied research typically leads to more knowledge about exposures and better measurement and dose assessment techniques, and formulates improved procedures for users of radiation and tools for emergency preparedness. Within STUK, the regulation of radiation practices gains the greatest direct benefit from radiation protection research (especially research on medical radiation, non-ionising radiation and natural radiation). Research has a fundamental role in improving the calibration and accuracy of the instruments for measuring of ionising radiation, electromagnetic fields and ultraviolet radiation. Nuclear reactor regulation and nuclear materials regulation benefit from research yielding better emergency management and more exact monitoring of occupational exposure. Regulation of nuclear waste and materials makes use of research results produced by the CTBT radionuclide laboratory and also benefits from environmental impact assessment and research on natural radiation. Emergency preparedness and radiological situation assessment rely heavily on the competence of several laboratories, in particular the Environmental Surveillance and Preparedness Laboratory. These units also perform environmental surveillance in Finland, which is one of STUK's regulative activities. In many cases, the interaction between research and regulatory functions develops through international standards and regulatory guides.

More fundamental research, which addresses health risks from radiation, has a more indirect connection with regulation, as it adds to the pool of knowledge used by the risk assessment organisations. However, studies conducted on the Finnish population are also directly relevant at the national level.

The Department of Research and Environmental Surveillance has four main functions: research, environmental surveillance, emergency preparedness and services. There are clear synergies between these different functions: research improves the competence and continuous development of surveillance, preparedness and service functions. The same methods and infrastructure are applied throughout these functions and the same QA system also supports work in the laboratories. The personnel are typically engaged in several functions, from research to services. Research is conducted by all laboratories and many research projects involve experts from the different laboratories. All laboratories are also involved in emergency preparedness and all permanent personnel have a specific role in STUK's emergency organisation. Two laboratories take part in surveillance of radiation in the environment: Environmental Surveillance and Preparedness, and Radionuclide Analytics. For radiation measurement services, the largest programmes are related to radon, the NPP environment and internal contamination. There are multiple contact points and synergies between the different activities. Environmental research, environmental surveillance and analytical services make use of the same sample treatment and analytical methods and know-how. Data generated by the services is also used for research purposes, as in the case of radon mapping or monitoring of the NPP environment. Research generates new methods and technologies for use in radiation emergencies and environmental surveillance. Emergency preparedness benefits from monitoring networks and routines. Last but not least, the income from the contracted services makes it possible to employ personnel and buy equipment so that these extra resources are available in case of a radiation emergency.

2.8 Co-operation with other research institutes and universities with related and overlapping interests

In Finland, STUK is the main – and in many areas the only – research institute conducting radiation protection research. There are therefore no real competitors at the national level. Expertise complementing STUK's know-how in radiation protection is actively sought via networking with other research institutes having their own specialisation. In some areas, especially in those related to emergency preparedness and environmental radioactivity analysis, the lack of other research units with expertise in radiation protection is becoming problematic, since there should be more capacity in that field in case of severe fallout situations. The number of employees in practically all government research institutes is, however, continuously declining. This has made it more difficult to find resources for joint research activities, as each institute has to prioritise its own mission. In Finland, research related to ionising radiation protection is carried out in the medical physics departments of universities/university hospitals, at the Technical Research Centre of Finland (VTT) and the Laboratory of Radiochemistry at the University of Helsinki. Research related to non-ionising radiation protection is carried out at the Institute of Occupational Health and the University of Kuopio. In addition, technical development has been carried out with several companies and a number of domestic collaborators and corporations have acted as suppliers of samples or data.

The foreign collaboration is extensive and has become increasingly important since Finland joined the European Union in 1995. The collaboration network includes partners in most EU countries, all Nordic countries, NIS countries (Russia, Kazakhstan, Ukraine and Belarus) and non-European countries such as the USA, Canada, Japan, China, Australia and South Africa.

2.9 Impacts on the ministry level

STUK is on independent regulatory and research organisation. Administratively, STUK comes under the Ministry of Social Affairs and Health. However, several other ministries (Fig. 4) deal with issues related to radiation and nuclear safety.

Many STUK research results and development projects are of direct benefit to different ministries and authorities in Finland. STUK also actively collaborates with the research institutes of the different ministries. The most important ministries and authorities using the research results are the following:

- **Ministry of Social Affairs and Health**
  Health risks of ionising and non-ionising radiation, preventive medicine, medical use of radiation, environmental health, occupational health, contacts with the WHO
- **Ministry of Employment and the Economy**
  Nuclear safety, nuclear security; EC Nuclear Energy Programme, contacts with the IAEA, industry and trade, industrial use of radiation
- **Ministry of the Interior**
  Emergency preparedness, environmental radiation surveillance
- **Ministry for Foreign Affairs**
  CTBT (Comprehensive Nuclear Test Ban Treaty) National Data Center and radionuclide laboratory. Contacts with UNSCEAR.
- **Ministry of the Environment**
  Radon in indoor air and drinking water, community planning, construction guidelines, environmental impact assessment of nuclear facilities; environmental health action plan jointly with the Ministry of Social Affairs and Health, radioactivity in the Baltic Sea and the North East Atlantic, Radioactivity in the Arctic areas; protection of the environment
- **Ministry of Defence**
  Nuclear and radiological threats, emergency preparedness, mobile/airborne radiation measurements; CBRN detection and protection

- **Ministry of Agriculture**
  Agricultural radiation countermeasures, radionuclides in the food chain, forests

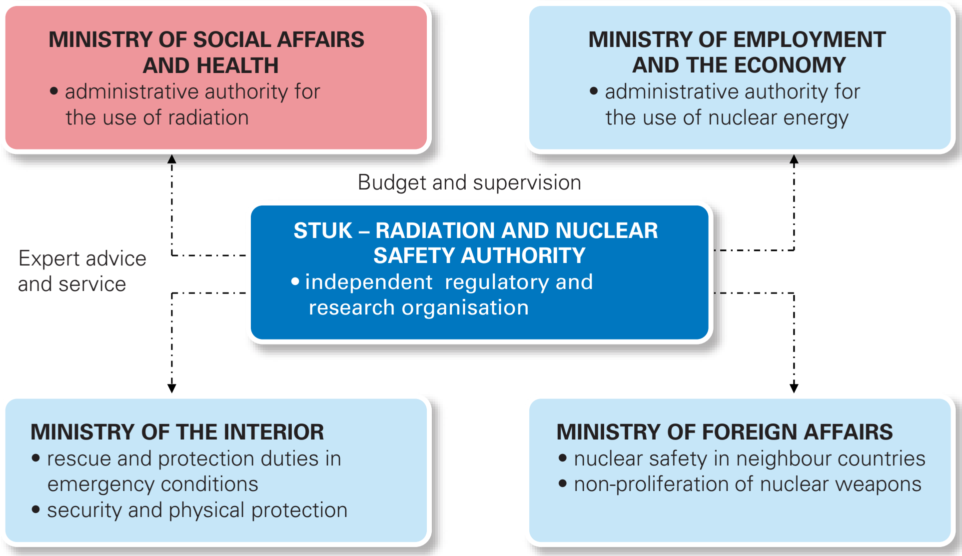


Figure 4. Main contacts between STUK and Ministries.

2.10 Impact on society

The results and conclusions of STUK research are passed on to decision makers and society in several ways. The implementation involves several ministries and authorities at country and municipal levels that have responsibilities related to radiation protection (health, environment, rescue service, community planning etc.). Books written by STUK experts are used in universities and professional level education and several STUK experts also have posts as university lecturers (docent). Advanced professional training in radiation protection is provided both at national and international levels. Joint seminars and emergency exercises are organised with several stakeholder groups. Knowledge on radiation protection is also mediated via research networks and projects involving stakeholders that aim at improved procedures and practises or new methods to reduce radiation exposure. This two-way communication also ensures that STUK receives valuable information and feedback from the key actors in the field. Information on research results and radiation protection is actively distributed to the general public and stakeholders.

Over the years, increasing attention has been paid to the exploitation and impact of STUK's research results. The exploitation plan is an integral part of the research project plan. At the international level, many of the research results are communicated via research networks or different working groups. Since Finland joined the European Union in 1995, STUK has obtained a strong position in European research programmes, especially in the Euratom Nuclear Fission programme. Currently, STUK is leading the major low dose risk programme (DoReMi Network of Excellence) aiming at sustainable integration of European research in this area. STUK has also provided a considerable input into the development of radiation protection standards of the European Commission via the Article 31 Group of Experts and commissioned services of DG TREN. STUK has also acted as a contracted support organisation to the EC in radiation and nuclear emergencies and nuclear security. STUK collaboration with WHO is extensive, covering public health aspects of nuclear and radiological emergencies, medical radiation and radon. STUK also has representatives in the committees and working groups of the OECD Nuclear Energy Agency (NEA). More recently, STUK experts have participated in the work of the ICRP (Committees 1 and 4) and UNSCEAR (observer), thus ensuring the exploitation of Finnish knowledge by the international risk assessment society.

Expert knowledge of the research personnel of STUK covers all areas of radiation protection, i.e. from basic research on the health effects of ionising and non-ionising radiation at the molecular level to daily monitoring of levels of radiation. This broad expertise has also enabled STUK's own technical product development whenever it has been needed.

As described in chapter 2.6, research results are distributed not only to the scientific society but also to the general public by publishing a popularised summary of each research article or report. Regarding communication with radiation users and other stakeholders, STUK scientists submit articles to professional journals in order to distribute the latest news on radiation research and radiation protection. STUK also publishes its own journal on radiation protection and nuclear safety (ALARA journal), which is essentially directed to the domestic radiation protection society. Experts of STUK also give lectures in various courses dealing with radiation, health effects or environmental protection, emergency preparedness or nuclear safety. More recently, also social media such as Facebook has been applied by STUK for information exchange in specified areas (Fukushima, radon).

STUK closely co-operates with educational institutions. In addition to joint research projects with universities, certain scientists of STUK act as permanent lecturers in universities. The new Radiation and Nuclear Safety book series has been welcomed as training material by several educational institutions.

Figure 5 illustrates how the ultimate goal of STUK research – impact on society – is built upon strong resources, clear processes, relevant deliverables and new knowledge and improved competence.

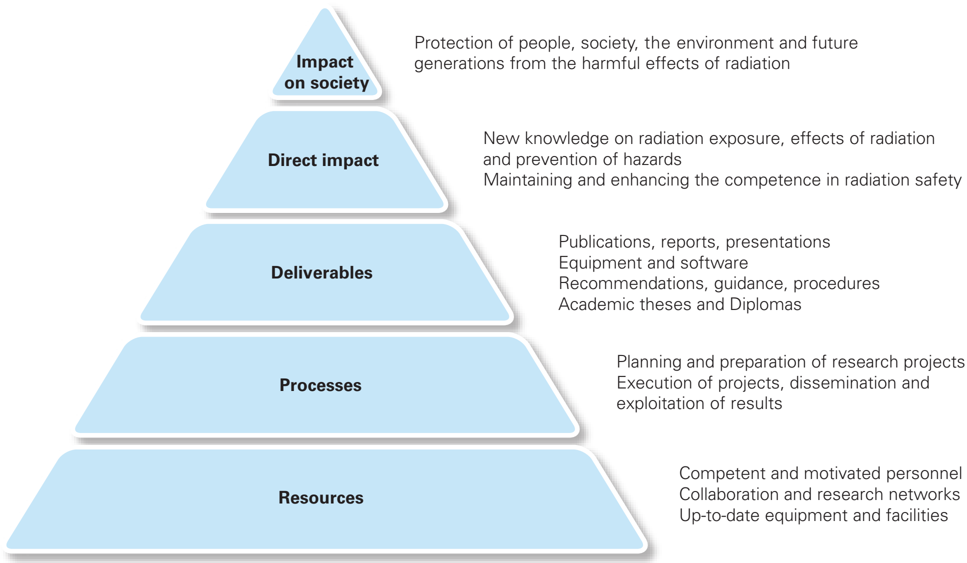


Figure 5. Impact of radiation safety research.

3 Resources and knowledge management

3.1 Personnel structure

The trends in personnel structure in the units performing research are illustrated in Figures 6 and 7. Overall, there has been a decline in the number of employees, in particular for the fixed-term personnel. The number of full person-years spent on research has varied between 72 and 51 during 2000–2010, with the lowest value in 2010 and a steady decline over the last decade (Figure 9, chapter 3.3).

The educational background of the staff in the units described above is illustrated in Figures 6 and 7. Currently, 55% of the permanent staff have an

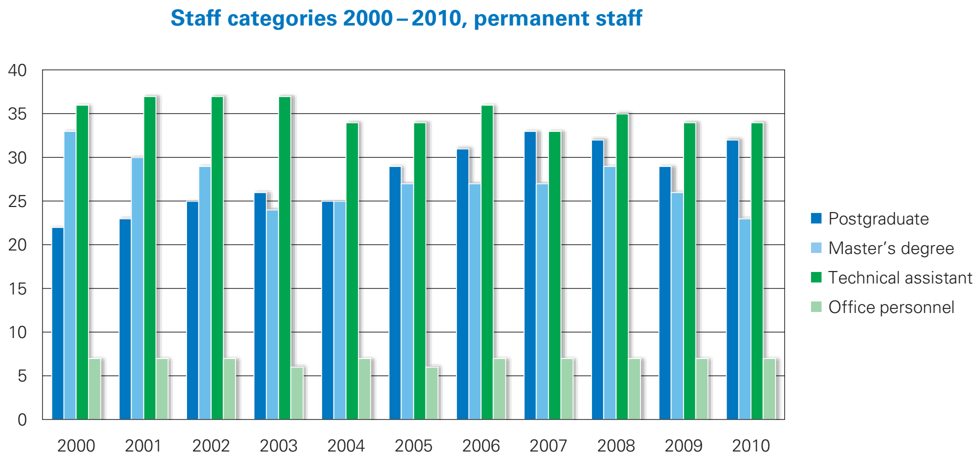


Figure 6. Staff categories from 2000–2010 among permanent staff of the units performing research.

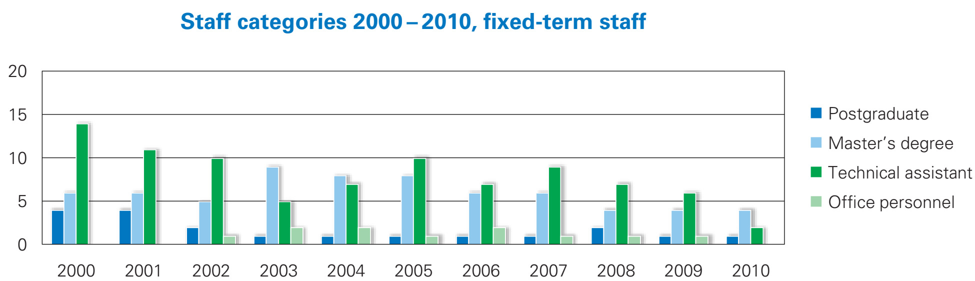


Figure 7. Staff categories from 2000–2010 among fixed-term personnel of the units performing research.

academic degree at the Master's level or higher. The educational background of scientists at STUK is almost entirely in the natural and life sciences, such as physics, nuclear physics, radiochemistry, chemistry, statistics, geology, genetics, biology, biochemistry, medicine and forestry. The technical sciences are also well represented. Thirty-three of the 100 persons with permanent positions have post-graduate level qualifications. Seven of the doctors are docents, i.e. lecturers in university departments. 25 Master's and 1 Licenciate degrees and 11 Doctorates were completed in 2005–2010. In addition, 5 graduate-level degrees were completed.

3.2 Recruitment of researchers

A large number of the permanent staff were engaged in the 1960s and the 1970s when the functions of STUK were expanded due to the nuclear test fallout, the discovery of the radon problem and the construction of nuclear power plants in Finland (see Fig. 1). As STUK is the main institution for research on radiation protection in Finland, there was relatively little turnover of staff until recently. Now, many of the staff members with long experience have retired, but this retirement wave will continue for the next few years. Many of the newly recruited researchers already have a doctoral degree, while in previous decades this was often achieved only after a long career at STUK. In 2010, the average age of the permanent staff at STUK was 47.3 years and that of the fix-term staff 39 years.

It takes several years to train as a scientist in a specialised field. A university education alone does not provide adequate expertise in radiation protection and, as Finland has no other strong research institutes in radiation protection, very few scientists with specialised training are directly available for the posts. External funding and shared-cost contracts have enabled the employment of fixed-term personnel, including students aiming at a Master's degree or doctorate. Many of these project researchers have later been engaged permanently by STUK, resulting in a more balanced age structure. Nevertheless, the transfer of knowledge from retiring experts to the new generation of radiation protection specialists continues to be important.

STUK started an extensive internal training programme on different aspects of radiation protection and nuclear safety in 2002, along with the publication of the new book series that has been used as training material (Paile 2002, Ikäheimonen 2003, Pöllänen 2004, Sandberg 2004, Tapiovaara 2005). Two more books in the series, concerning electric and magnetic fields and optical radiation, were recently published (Nyberg and Jokela 2006, Pastila 2009).

In Finland, there are no specialised PhD Schools in the field of radiation protection. However, postgraduate training has been provided by the Doctorate

School on Public Health, Doctorate School for Environmental Health and Doctorate School on Systems and Risk Analysis.

3.3 Finance

All STUK activities are divided into seven action areas: research, nuclear safety regulation, radiation safety regulation, emergency preparedness, environmental surveillance of radiation, external services and communication. Costs are divided up among these action areas. Overheads from administration, internal services, renting expenses and other costs are also divided among the action areas according to internally agreed procedures.

During the past few years, research has accounted for some 20% of STUK's total costs. The construction of a new nuclear reactor unit in Olkiluoto and planning for two additional ones has increased the accounting of nuclear safety compared to research. The breakdown of STUK costs among the different action areas in 2010 is illustrated in Figure 8.

Research has earlier been STUK's biggest action area in terms of human resources, but during recent years, nuclear safety has become the largest one. About 14–19% of total human resources were devoted to research purposes during the period 2005–2010, while in 2000–2004 this figure was 19–24% (Fig. 9). The change is even greater when compared to the 1990s, when more than a quarter of the resources were devoted to research purposes. In addition

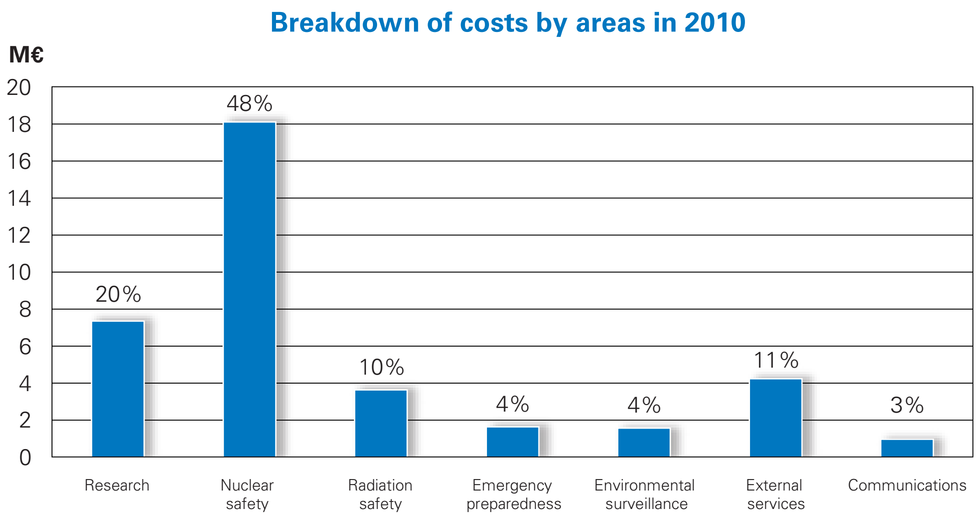


Figure 8. Breakdown of total STUK costs among the different action areas in 2010.

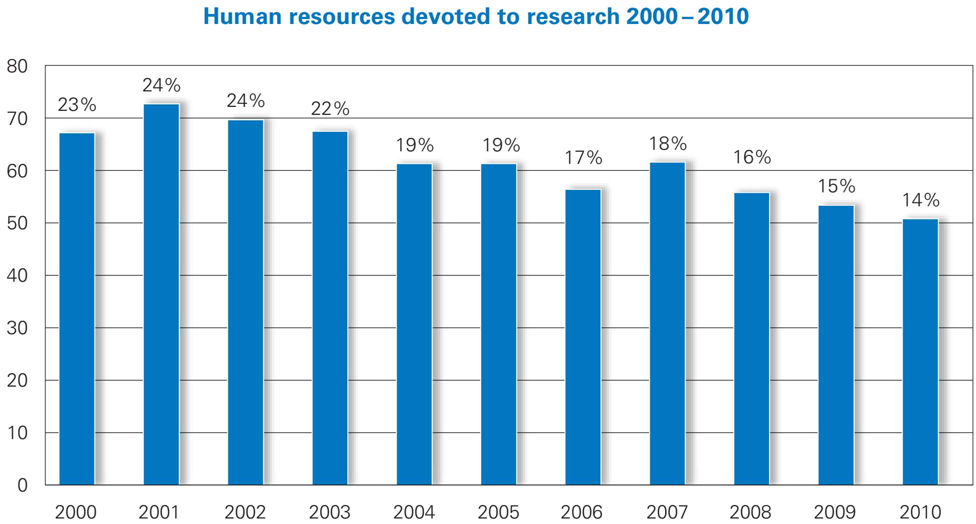


Figure 9. Person-years devoted to research at STUK in 2000–2010. The percentages in the figure indicate the proportions of STUK's total human resources.

to the fact that the volume of nuclear safety has increased, other reasons for the decreasing relative proportion of research have been the increase in other actions, such as internal development projects of STUK, expert service projects and environmental surveillance and preparedness, which have taken the time of researchers. The reduction in the number of fixed-term personnel also indicates that less time is now spent on time-consuming field and laboratory work. Much of this reduction has been dictated by the government productivity programme, which is limiting the number of employees.

The small variations in person-years reflect the number of temporary employees in short-term research projects. In 2010, 50.8 person-years were allocated to research.

The total cost of research has been around EUR 7 million during the past few years (Fig. 10). From 1995 until 2003, the total costs increased slightly, along with the general cost index and due to higher overhead costs. Direct research costs varied from EUR 3.3 million to 4 million between 2005–2010.

In recent years (since 2003), all government sectors have faced requirements for improved productivity. This has involved reductions in the number of personnel, which means that the focusing of research activities and considerations on a critical mass has become increasingly important.

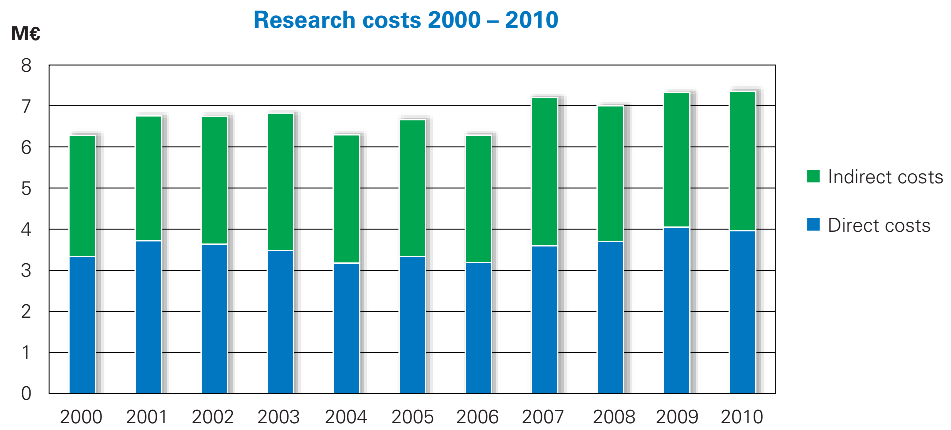


Figure 10. Trends in research costs from 2000 to 2010.

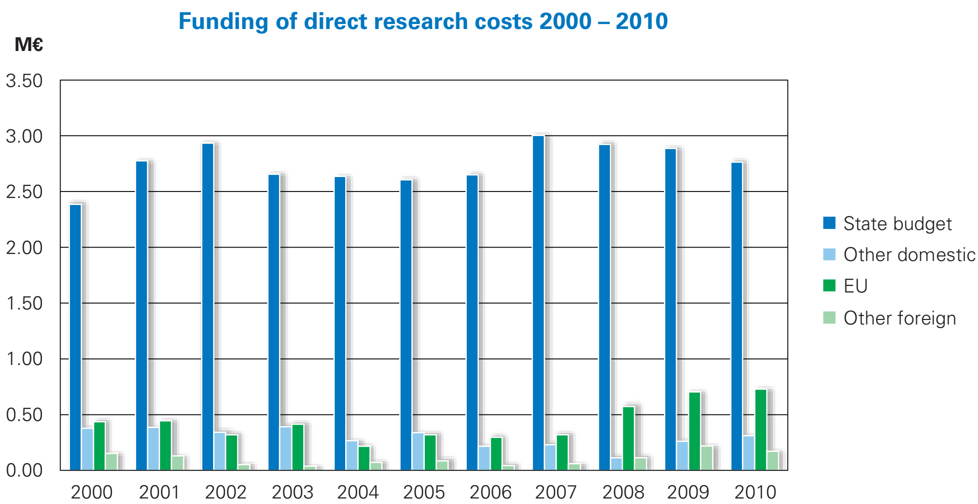


Figure 11. Sources of research funding at STUK in 2000–2010.

Sources of funding

Most of the research funding comes from the state budget, and the overhead costs shown in Figure 10 are entirely covered from budget funding. The overhead costs include administration, rents and internal services. Direct costs can be allocated to several funding sources. In Figure 11, the funding of direct research costs is divided among domestic and foreign sources. In addition to the state budget, STUK domestic research funding has been obtained mainly from the Academy of Finland and from the National Technology Agency (TEKES).

Since 1995, when Finland joined the European Union, the international funding has mainly come from the European Commission. Other international sources include Nordic Nuclear Safety Research (NKS) and CRTI/Canada.

The proportion of research funding from external sources has increased over the past few years (Table II). External funding annually totals about EUR 600–1 200 k. In addition, part of the training of personnel is carried out as shared-cost projects.

The role of income from services in funding is more significant than the external funding of research. Services provided by STUK consist of radiation measurements, calibrations, training and expert services to be agreed case-by-case. In 2005–2010, STUK received 4–8 times more income from services than from co-financed research projects. In 2010, the external funding of STUK research totalled EUR 1 213 k, which corresponds to about 26% of the income from services during the same period (EUR 4 605 k).

Table II. State budget for STUK, total research costs and proportion of research costs from the state budget in 2005–2010.

Year	State budget (k€)	Total research costs (k€)	Research costs from state budget (k€)	Portion of research from total budget
2005	11 527	6 686	5 945	52%
2006	11 762	6 311	5 733	49%
2007	12 539	7 219	6 610	53%
2008	12 693	7 023	6 226	49%
2009	13 020	7 352	6 166	47%
2010	13 314	7 377	6 164	46%

Financial resources for the different sectors of research

For accounting, research is divided into ten focus areas:

- Health effects of radiation
- Use of radiation
- Occurrence and mitigation of natural radiation
- Environmental research
- Preparedness for radiological threats and emergencies
- Dosimetry and metrology
- Non-ionising radiation
- Nuclear safety
- International collaboration (outside projects)
- National collaboration (outside projects)

As mentioned before, STUK does not itself carry out nuclear safety research projects (safe use of nuclear power and nuclear waste management) commissioned by the authorities. This research is conducted by organisations outside of STUK, particularly following the national funding system on nuclear safety in 2004 (Nuclear Energy Act §53). Currently, the amount of nuclear safety research at STUK is negligible.

The categorisation of research areas was slightly redefined in 2008 to better reflect the ultimate purpose of the activity (effectiveness). Previously, radioecology and emergency preparedness were considered as one category, but they have now been separated into environmental research and preparedness for radiological threats and emergencies. In 2010, the total cost of research was EUR 7 289 356, broken down among the different research activities as shown in Figure 12. The health effects of radiation (26%), preparedness for radiological threats and emergencies (21%) and environmental research (17%) were the largest research areas, followed by the occurrence and mitigation of natural radiation (8%), dosimetry and metrology (8%), non-ionising radiation (5%) and the use of radiation (4%). The relatively large amount of costs related to international research collaboration outside projects (10%) is partly explained by the organisation of the European IRPA congress in 2010.

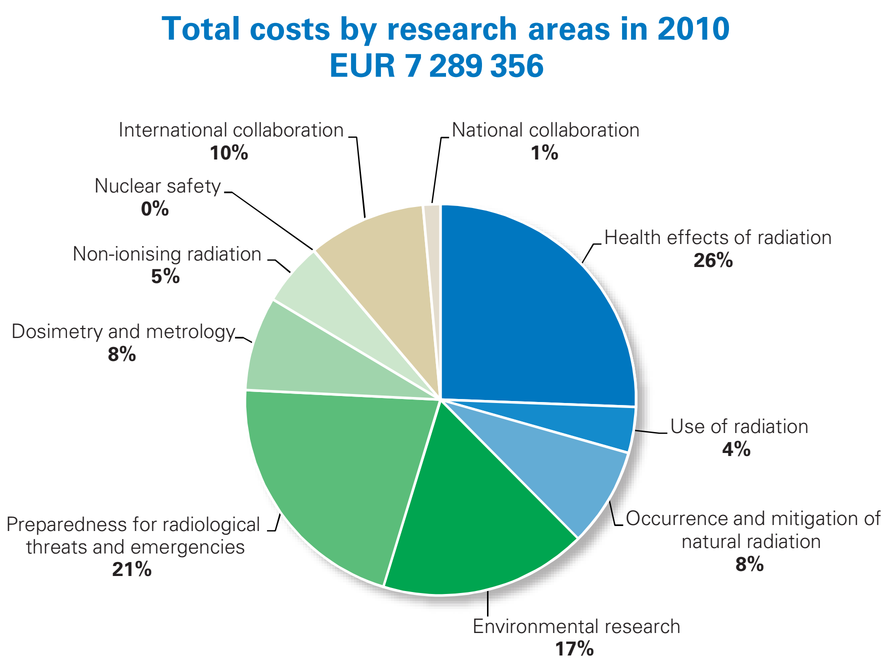


Figure 12. STUK research costs in different research areas in 2010.

3.4 Research facilities

STUK research is conducted at two different sites. Most of the research facilities are in one building in eastern Helsinki, and the rest at the regional laboratory in Rovaniemi, about 800 km north of Helsinki, on the Arctic Circle. The Regional Laboratory in Northern Finland specialises in studies on sub-Arctic and Arctic ecosystems.

The total floor area of the main building in Helsinki is about 14 500 m^2, of which about 4 600 m^2 comprises laboratory facilities with special structures and ventilation. The main building dates from 1994. The laboratory ventilation is isolated from the system ventilating the normal office rooms.

The facilities comprise a total of 50 laboratory rooms for the pre-treatment of samples, radiochemical and biological treatment and analysis of samples, radioactive and X-ray measurements, non-ionising radiation, and the calibration of measuring instruments. STUK has seven laboratory rooms for low-background alpha, beta and gamma measurements. The rooms are constructed of a special concrete (olivine rock and special cement) containing an extremely low amount of natural radioactive elements and are equipped with a special air ventilation system (air conditioning, excess filtering of incoming air, and exhaustion of radon exhaling from construction materials before radon enters the room air). Monitoring of temperature and humidity in the measurement rooms is also arranged. The main building additionally contains one laboratory for X-ray studies and three laboratories for the calibration of radiation measuring instruments. The laboratory facilities for cellular and molecular biology are isolated from the other research facilities. The laboratory for handling substances with high amounts of radioactivity is located in the sub-basement of the building.

Laboratories for non-ionising radiation are located on the ground floor, except for the solar UV measurement chamber, which is on the roof of the main building. Measurements of electric and magnetic fields and Specific Absorption Rate, device testing and calibration are performed in a radio laboratory including two microwave anechoic chambers of $2 \times 2 \times 3.5$ m^3 and of $2 \times 2.5 \times 3.6$ m^3 in size. Measurements of optical radiation, device testing and calibration are performed in the optical laboratory and a solar measurement chamber on the fenced roof. The interiors of both the optical laboratory and solar chamber are painted black. The measurement site in the optical laboratory is also screened with a black curtain from the rest of the room.

The facilities of the Regional Laboratory of Northern Finland in Rovaniemi, used for the pre-treatment, radiochemical analysis and measurement of environmental samples, comprise 10 laboratories that are located together with the Geological Survey's Northern Finland Office.

STUK has a large number of high-quality measurement instruments used for radiochemical and biological treatment, the analysis of environmental samples and direct measurements of radioactivity in the environment and in people:

- Fifteen high-resolution gamma spectrometers
- Three alpha spectrometer systems
- Six liquid scintillation spectrometers
- Three proportional counter systems
- Tritium and carbon analysers
- Other equipment (AAS and MARS)
- SONNI mobile laboratory
- Two whole-body counters: stationary and a mobile unit
- Air sampling and monitoring system
- PANDA - Particles And Non-Destructive Analysis
- Radiation biology equipment.

Confidence in the performance of the equipment is maintained by regular calibrations and servicing, routine checks and control charts. To ensure the high quality of analytical systems, considerable investments in specific technologies and equipment have been made during 2005–2010.

The Laboratory Information Management System (LIMS) was installed and tailored for the use of the laboratories during 2003–2005. The system helps in the management of laboratory work, data management and reporting in the department. However, this does not meet the needs of requirements set for the LIMS system today or the needs of the new organisation at the department. Therefore, a new, uniform system is under development. The main aim of the new LIMS system is to obtain a real-time laboratory information management system that can help more in the follow-up of samples in the laboratory, work progress and traceability of the work, and not only for samples. For gamma spectrometric measurements, an open-source Linux based database named Linssi has been developed. It supports an automatic analysis pipeline and provides a convenient interface for viewing gamma spectrometric analysis results. The Linssi database will be a part of the new LIMS system for managing gamma spectrometric measurements.

In addition, a data register called STURE is under development. In the STURE register, information from the research data, registers and publications is stored.

3.5 Supportive functions

Internal administrative support functions include financial and personnel administration. The information services at STUK include a high-quality library, which acts as the central library for radiation and nuclear literature in Finland. On-line scientific databases are readily available via the internal computer network. Support in Information Management is provided by EDP, DSS and IS units, which support the computer network services, hardware installations and maintenance, data system services as well as information services. All employees at STUK have their own computer connected to the network. The network acts as an essential communication route, offering not only e-mail and the Internet, but also the Intranet, an electronic library containing all the documentation related to the management and administration of STUK. STUK's web site provides information in Finnish, Swedish and English. A Document Management System is in use.

Internal training on different aspects of radiation protection has been carried out on a frequent basis. The training modules are based on the new Radiation and Nuclear Safety book series. Internal training is also provided to improve skills needed to use the software (office programs, database construction, programming), and in management and communication. Tailor-made courses are also organised to meet the needs of specific personnel groups. Twice a year there is a 2-day introductory course for new employees describing the different activities of STUK. Training at outside organisations is also actively supported. Occupational health care, STUK's own gym and organised fitness activities help in maintaining the physical and mental well-being of the personnel.

4 Units conducting research

The overall responsibility for the research process, in particular the strategy and quality of research, lies with the Research Director, positioned in the Director General's office. The Research Director of STUK, Professor Sisko Salomaa, PhD, docent (genetics), also participates in international and national collaboration. In addition, she coordinates strategically important research projects such as the DoReMi Network of Excellence aiming at the sustainable integration of European low dose risk research. Salomaa, the prior head of the Department of Research and Environmental Surveillance, took over the new position in late 2007. The organisational structure of STUK is illustrated in Figure 13.

STUK research activities are carried out in the laboratories and units of two departments, the Department of Research and Environmental Surveillance and Department of Radiation Practices Regulation, as well as the unit of Non-ionizing Radiation Surveillance (see Figures 14 and 15, respectively).

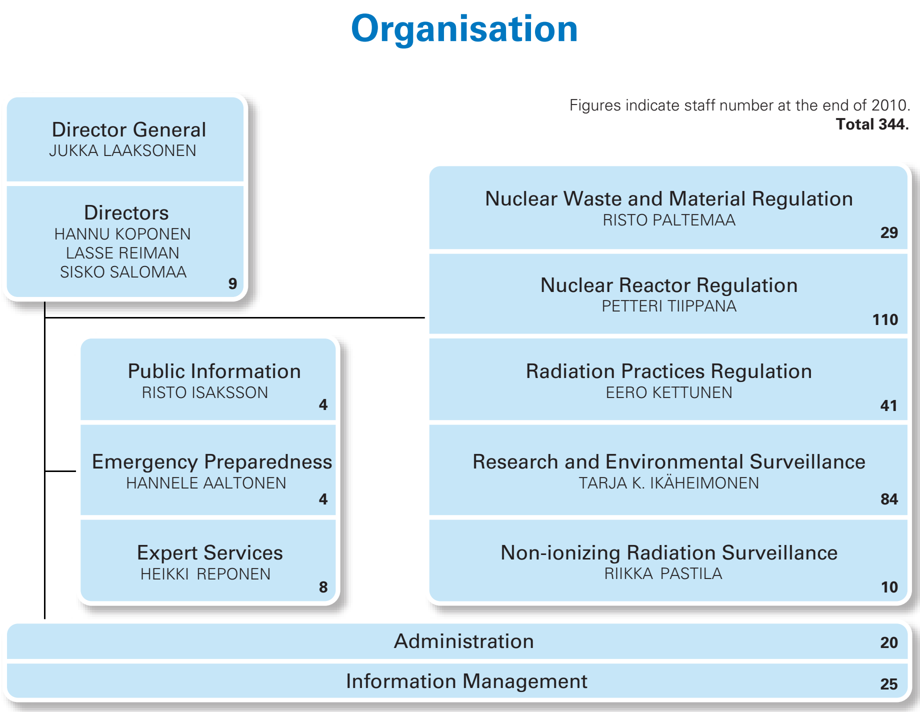


Figure 13. Organisation of STUK (June 2011).

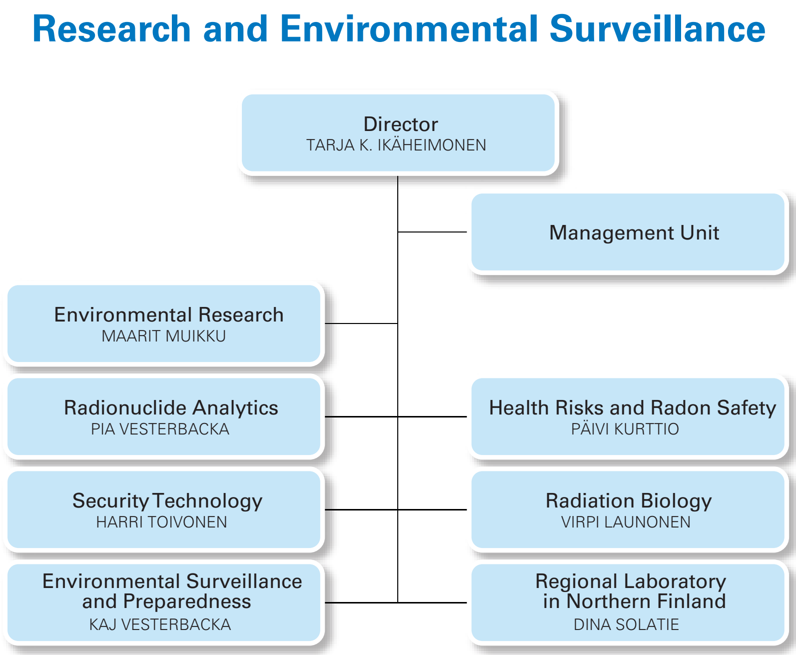


Figure 14. The Department of Research and Environmental Surveillance.

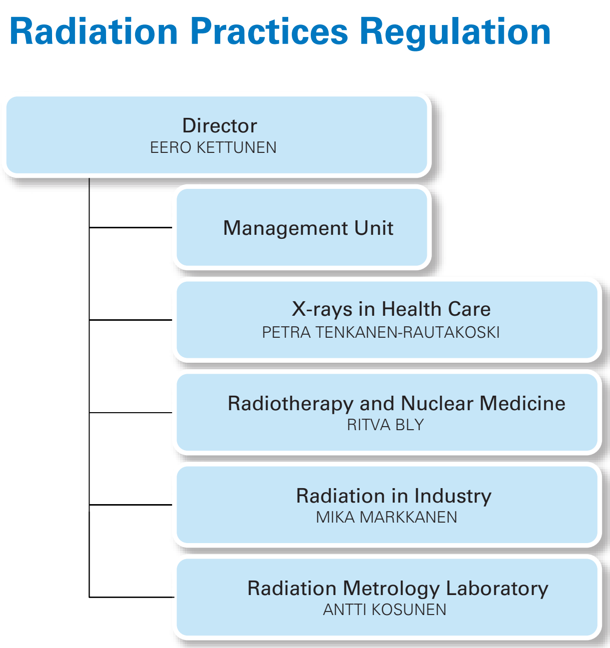


Figure 15. Organisation of the Department of Radiation Practices Regulation.

4.1 Department of Research and Environmental Surveillance, Management Unit

Research and Environmental Surveillance is one department of STUK being, according to its name, responsible for a major part of the research at STUK and environmental surveillance of radiation in Finland. The Departement is also responsible for off-site emergency preparedness and additionally takes part in the strategic planning of emergency preparedness as well as expert services, in particular radiation and radioactivity measurements. The research performed by the department focuses on prevention and limitation of the harmful effects of radiation as well as supporting STUK's regulatory role. The goal of environmental surveillance is to be always aware of the environmental radiation to which the population is exposed and to estimate doses to Finns through different exposure pathways. The department is also responsible for the maintenance and development of laboratory and field capabilities for radiological emergencies.

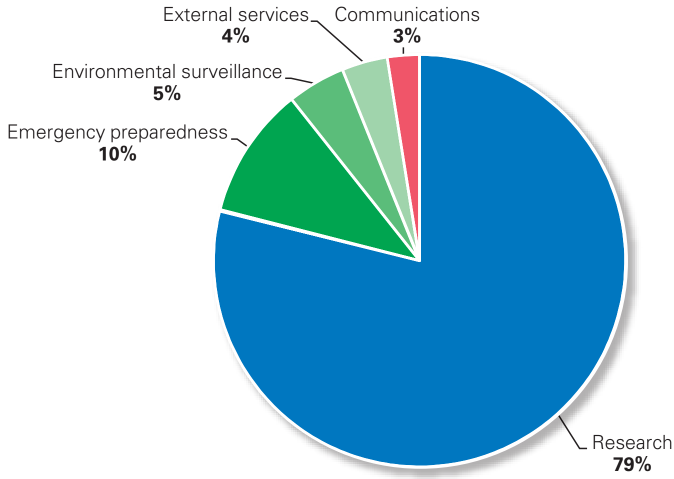
At the end of 2010, there were seven laboratories and a Management Unit in the Department of Research and Environmental Surveillance. The Management Unit and six of the laboratories are located in Helsinki (Health Risks and Radon Safety, Environmental Research, Radionuclide Analytics, Environmental Surveillance and Preparedness, Security Technology and Radiation Biology) and one in Rovaniemi (Regional Laboratory in Northern Finland). At the end of 2010 the number of personnel in the department was 84. In addition, a number of students, summer trainees and other temporary persons have worked in the department.

4.1.1 Role of the Management Unit

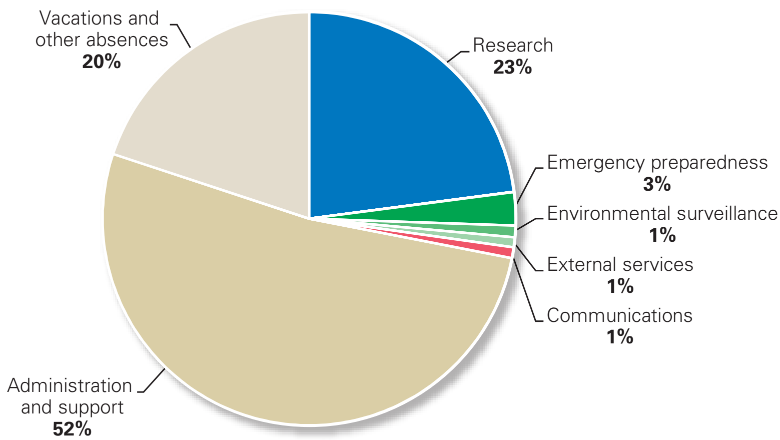
Responsibility of the Management Unit of the Department of Research and Environmental Surveillance is to ensure sufficient operational preconditions in the laboratories of the department to fulfil the approved actions plans and tasks of the laboratories. The Management Unit offers managerial and secretarial services to the laboratories and also performs tasks and projects itself related to the substance of the department, in particular emergency preparedness and radioecology. The overall goal of the department is to produce, through research, radiation surveillance, response to exceptional radiological situations and expert services, such knowledge that serves not only STUK's needs but also the needs of other domestic and foreign authorities, different stakeholders and the whole population of Finland, as well as the international scientific community. The goal of the Management Unit is to ensure that the resources of the department will not diminish and that the department is able to respond, without any delay, to all exceptional radiation observations and to other abnormal incidents related to the department's branch. Within STUK, management of the Department of Research and Environmental Surveillance aims to strengthen the co-operation between different departments of STUK and to clarify the working procedures of joint projects with other departments.

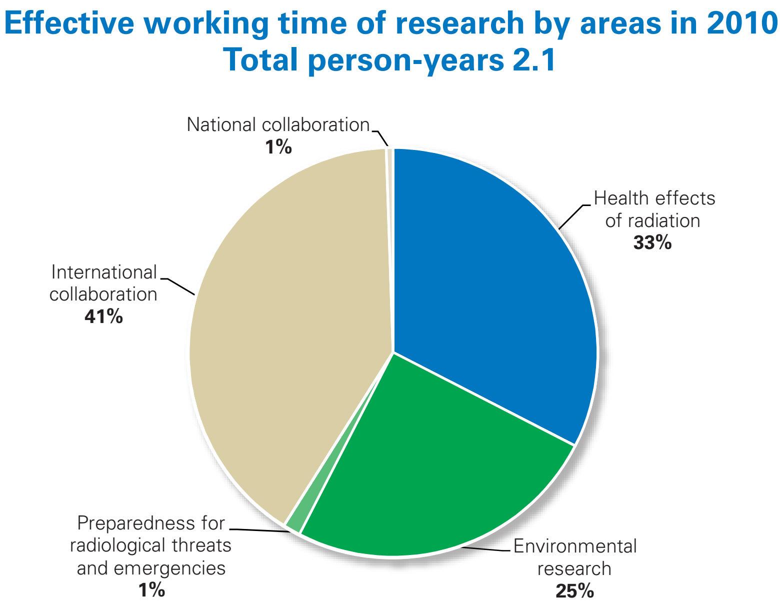
Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures.

Total costs 412 k€ distributed by sectors in 2010



Effective working time by sectors in 2010
Total person-years 9.2





4.1.2 Description of research activities

The Management Unit of the Department of Research and Environmental Surveillance is also directly involved in the RTD activities of STUK, because the Director, Deputy Director and the Senior Adviser are personally engaged in some research and development projects. The Management Unit has been involved in the following RTD projects during the past five years:

- EURANOS, European Approach to Nuclear and Radiological Emergency Management and Rehabilitation Strategies, Euratom FP6, 2004–2009;
- FUTURAE, A Future for Radioecology in Europe, Euratom FP6, 2004–2009;
- DETECT, Design of optimised systems for monitoring of radiation and radioactivity in case of a nuclear or radiological emergency in Europe, Euratom FP7, 2010–2013;
- USVA, Surveillance Network for Ambient Radiation Dose in Finland, national development work, 2000–;
- KETALE, Centralised Data System for Managing Various Dispersion and Dose Calculation Results, national development work, 2006–;

The main results from these projects are described in more detailed in the later sections of this report. The Management Unit was in a key role when the Nordic Radiation Protection Society arranged the Third European IRPA Congress in Helsinki in June 2010.

4.1.3 Personnel

The Director is responsible for the overall management and leadership of the department with help of the Deputy Director. In line with the STUK strategy, the Director defines annual and long-term objectives and annual action plans for the department. The Director personally co-ordinates STUK's activities related to the protection of the marine environment of the Baltic Sea and acts as a board member of the Nordic Nuclear Safety Research (NKS). The Director also participates in and co-ordinates domestic and international projects to the extent separately agreed. The Director reports to the General Director of STUK. The Deputy Director leads one of the core processes of STUK, surveillance of environmental radiation in Finland, and the off-site emergency management activities of STUK. The Deputy Director has also acted as the contact for the Euratom Fission research programme, the Committee of the Articles 35–36 of the Euratom Treaty, and the nuclear and radiation safety activities within the Council of the Baltic Sea States (CBSS). The Deputy Director reports to the Director.

The staff of the Management Unit also includes the Senior Adviser, Project Planner, Management Assistant and the five Assistants. The Assistants provide secretarial services to the six laboratories of the department and take care of finishing publications for printing. The Management Assistant provides secretarial services to the Director and the Deputy Director, and reports some common matters to the whole department (data and document management, economy, etc.). The Senior Adviser focuses on radioecological research, especially in the forest environment and agriculture. The Senior Adviser also acts as a mentor to younger scientists in the department. The Project Planner, who reports to the Research Director, assists in the management of some international research projects and maintains contacts with foreign research partners. All other staff members report to the Deputy Director. The personnel of the Management Unit are listed below.

Tarja K. Ikäheimonen, PhD (Radiochemistry), Director
Management, research, radioecology, emergency preparedness

Raimo Mustonen, PhD (Physics), Deputy Director
Management, emergency preparedness, expert services

Aino Rantavaara, MSc (Radiochemistry), Senior Adviser
Radioecology, forest and agricultural ecosystems

Liisa Sirkka, MSocSc, Project Planner
Project management, project planning

Samu Inkinen, Management Assistant
Secretarial services, data and document management

Tuija Huotari, Assistant
Secretarial services

Jaana Joenvuori-Arstio, Assistant
Secretarial services, English language check-ups and translations

Nina Sulonen, MSc (Arch.) student, Assistant
Secretarial services, publication layout and management

Raisa Tiililä, Assistant
Secretarial services, quality management

4.2 Health Risks and Radon Safety

The Health Risks and Radon Safety Laboratory was formed from the Epidemiology Laboratory and the Radon Safety Laboratory at the beginning of 2010. All activities and personnel in these laboratories at that time were merged. The Epidemiology Laboratory was separated from Radiation Biology Laboratory in 2005. At the beginning of 2007 the Radon Safety Laboratory continued the indoor radon activities of the Natural Radiation Laboratory, while the activities concerning natural radioactivity in household water were moved to the laboratories of Environmental Research and Radionuclide Analytics.

4.2.1 Key words and specific technologies

Radon, indoor air, radon mitigation, health risks, epidemiology, statistics, uranium, drinking water, cancer, cataract, biological monitoring, RF-EMF, mobile phones, meningioma, glioma, natural radiation, passive alpha track radon detector, radon monitors, micromanometers, air flow meters

4.2.2 Description of laboratory activities

The Health Risks and Radon Safety Laboratory is responsible for:

- research on health risks associated with ionising and non-ionising radiation
- research on radon in indoor air
- statistical support for research
- emergency preparedness and response as part of STUK's organisation
- measurement services for indoor air radon concentrations and calibration
- communication and training on the health risks of radiation and radon in indoor air.

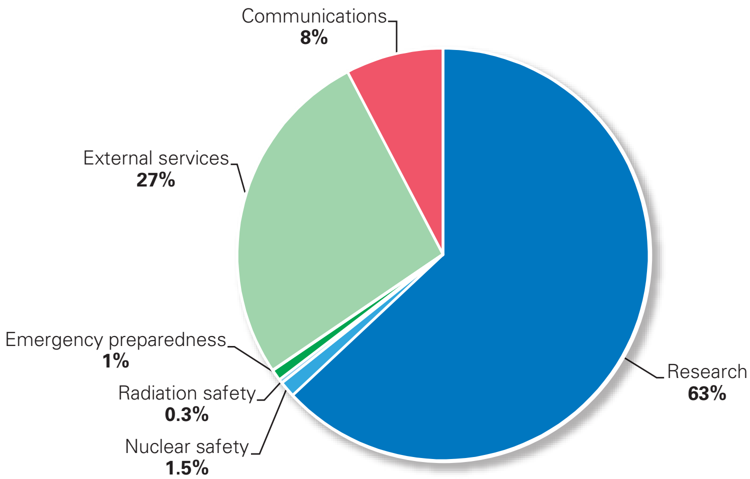
The Laboratory actively participates in national and international research programmes. Funding for research projects has been received from national funding agencies (Academy of Finland, National Technology Agency, Finnish Cancer Organisations, Ministry of Social Affairs and Health, Finnish Work Environment Fund) and international funding agencies (EU 7th Framework Program, Executive Agency for Health and Consumers).

Research 2005–2010

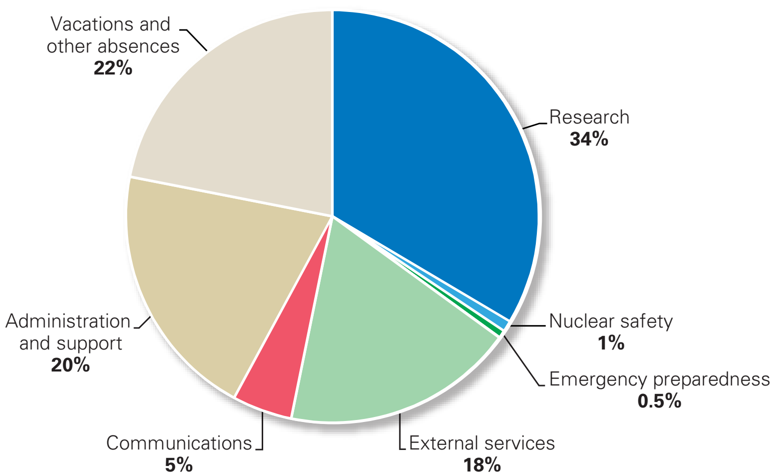
During 2005–2010 the personnel in the Laboratory were involved in research projects on the health effects of radiation (epidemiological studies on environmental, occupational and medical radiation and health, and the aetiology of brain tumours and health effects of mobile phones) and the occurrence and mitigation of natural radiation. These activities have been continued in the current laboratory. The main results (chapter 6) of 2005–2010 research projects can be found under the research areas of 1) health effects of radiation and 2) occurrence and mitigation of natural radiation.

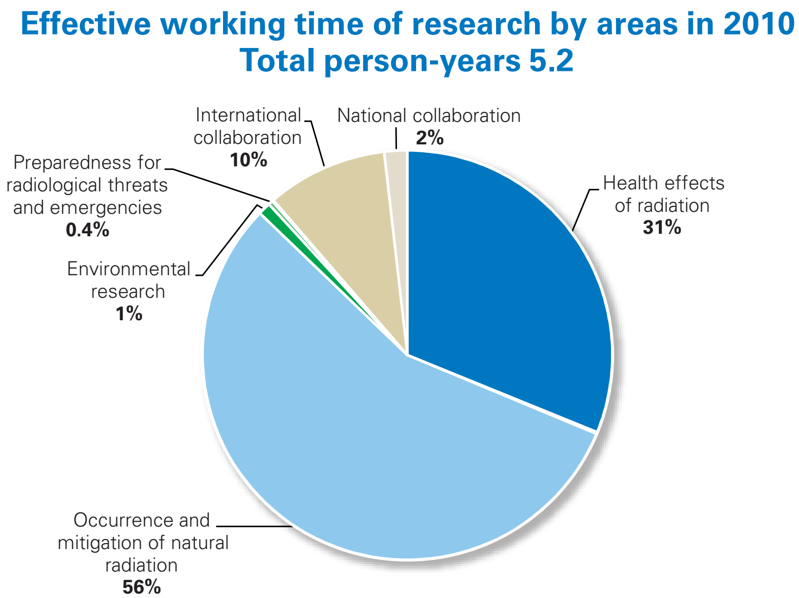
Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures.

Total costs 1 847 k€ distributed by sectors in 2010



Effective working time by sectors in 2010
Total person-years 15.6





4.2.3 Personnel

The personnel in the Health Risks and Radon Safety Laboratory at the end of 2010 are listed below:

Päivi Kurttio, PhD (Environmental Health), Head of Laboratory
Management, epidemiology, uranium, emergency preparedness and response

Hannu Arvela, DTech (Physics), Research Professor
Occurrence, remedial measures and prevention of indoor radon

Anssi Auvinen, MD, PhD (Epidemiology), Research Professor (part-time affiliation), Professor of Epidemiology at the University of Tampere
Radiation epidemiology, health effects of radiation, ionising radiation and electromagnetic fields

Wendla Paile, MD (Medicine), Chief Medical Officer
Health effects of radiation, emergency preparedness and response

Karl-Heinz Hellmuth, (PhD), Senior Scientist
Radionuclide migration in the geosphere

Eeva Salminen, MD, PhD, Medical Scientist (part-time affiliation),
Adjunct Professor at the University of Turku (Radiation Oncology)
Health effects of radiation, medical use of radiation

Sirpa Heinävaara, DSocSc, Statistician
Statistics, mobile phones

Olli Holmgren, DSc (Tech.), Scientist
Occurrence, remedial measures and prevention of indoor radon

Taina Ilus, PhLic (Organic Chemistry), Scientist
(part-time affiliation, retired 1.2.2011)
Data management and analysis

Heikki Reisbacka, BSc (Geology), Scientist
Indoor radon measurement services, radon at workplaces

Tuomas Valmari, DSc (Tech.), Scientist
Occurrence of indoor radon

Salla Blomberg, Research Assistant
Indoor radon measurement services

Tiina Oinas, Laboratory Engineer
Indoor radon measurement services

Hanna Niemelä, Laboratory Engineer
Indoor radon measurement services

Malla Salmén, Laboratory Operator
Indoor radon measurement services

4.3 Environmental Research

The Environmental Research Laboratory was formed from the previous laboratories of Radioecology and Radiation Hygiene. The laboratory also adopted functions related to the research on drinking water previously carried out by the Natural Radiation Laboratory. The organisational change took place in 2007.

4.3.1 Key words and specific technologies

Natural and artificial radionuclides, freshwater and marine radioecology, agricultural radioecology, forest radioecology, exposure pathways, radiation protection of the environment, drinking water, water treatment, radionuclides in the food chain, food safety, countermeasures, internal radionuclide contamination, internal radiation dose assessment, whole-body counting, bioassay, internal contamination and radiation doses of workers, internal doses of the population and population groups, building materials, stationary whole-body counter with scanning techniques, mobile whole-body counter, lap geometry counters, thyroid counters, HPGe detectors for low-energy gamma emitters

4.3.2 Description of laboratory activities

The Environmental Research Laboratory concentrates on radioecological research and dose assessment. The radioecological research of the laboratory encompasses several pathways and activities that cause exposure from both naturally occurring and artificial radionuclides in the agricultural, seminatural and aquatic food chains. One of the main areas of research is quantification of the environmental transfer of radionuclides through experimental studies, also designed for purposes of dose assessment and modelling, and planning of emergency response. The Laboratory also carries out research on countermeasures and the development of restoration management for agricultural land, foodstuffs, water supply networks and forests. In addition, the Laboratory participates in the development of radiation protection of the environment. The Laboratory is responsible for surveillance and research on artificial and natural radionuclides in humans. The radiation exposure for various population groups of people is determined using both direct and indirect methods. Activities also include research on factors influencing internal radiation exposure with special emphasis on metabolic and radioecological aspects.

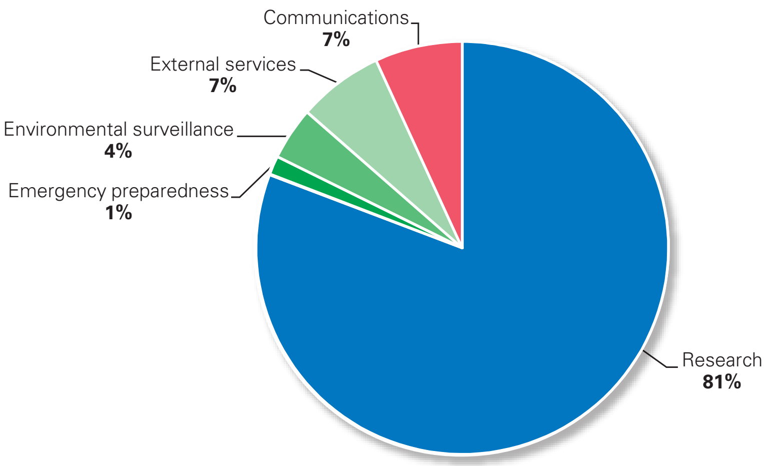
In emergency situations, the Laboratory is prepared to give advice on radiation issues in the fields of food and water supply and the forest industry. In addition, the Laboratory is responsible for the determination of internal contamination of people in emergency situations. The Laboratory is also responsible for the thyroid monitors placed in about 15 hospitals around the country, for the calibration and maintenance of these instruments as well as training of the users of the monitors. The intention is that the hospital personnel would be prepared to perform thyroid measurements locally in emergency situations to assist STUK in creating an overview of the radiation situation in Finland.

A part of the Laboratory's activities consists of expert services for enterprises. The main service is the control of internal contamination and estimation of the organ and total body doses of nuclear power plant and other radiation workers.

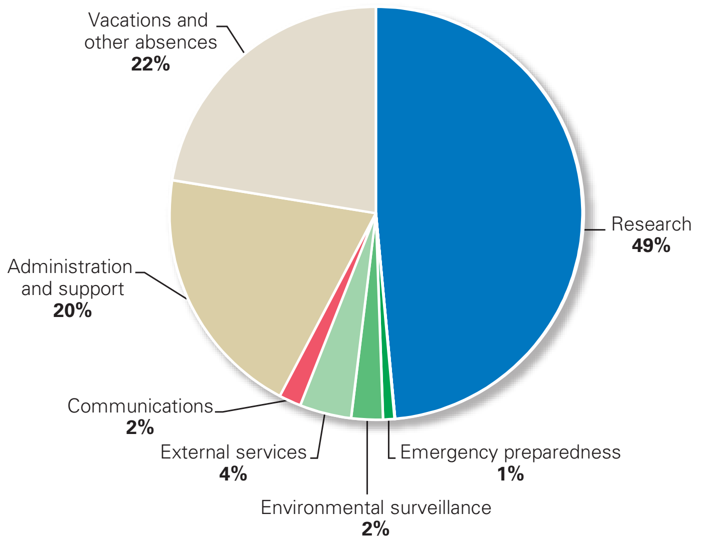
The Laboratory also contributes to communication and training, including information bulletins to the public on radionuclides in foodstuffs and drinking water, communication with and the delivery of information to the media as well as communication with stakeholders, customers and interest groups.

Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures.

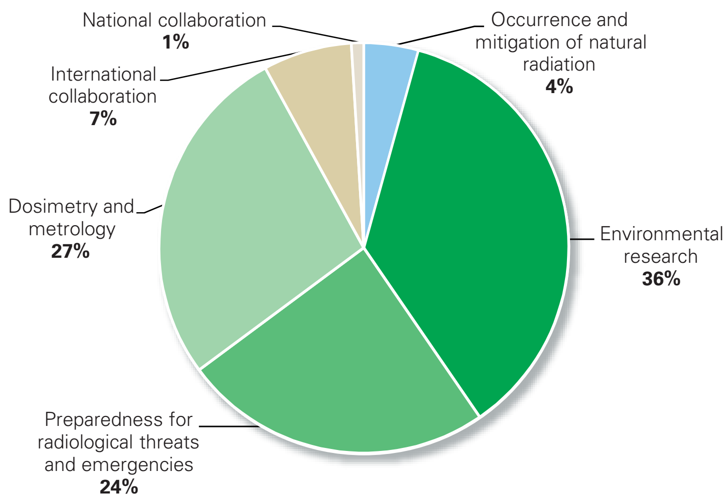
Total costs 945 k€ distributed by sectors in 2010



Effective working time by sectors in 2010
Total person-years 8.1



Effective working time of research by areas in 2010
Total person-years 3.9



4.3.3 Personnel

The personnel in the Environmental Research Laboratory at the end of 2010 are listed below.

Maarit Muikku, PhD (Physics), Head of Laboratory
Management, radiation protection, internal dose assessment, radiohygienic and radioecological studies, emergency planning and preparedness

Jussi Huikari, PhD (Physics), Senior Scientist
Internal dose assessment, Monte Carlo simulations, radiohygienic studies, emergency preparedness, quality assurance

Iisa Outola, PhD (Radiochemistry), Senior Scientist
Freshwater and marine radioecology, radiochemistry, emergency preparedness

Sauli Pusa, MSc (Physics), Scientist
Maintenance and development of whole-body counter systems, measurement methods, quality assurance, internal dose assessment

Tuukka Turtiainen, MSc (Radiochemistry), Scientist
Natural radioactivity in household water, foodstuffs and building materials, water treatment methods, water supply security, radiochemistry

Virve Vetikko, MSc (Biology), Scientist
Ecology, radioecology of forests, radiation protection of the environment

Eila Kostiainen, BSc (Radiochemistry), Scientist
Radioecology of agricultural and seminatural ecosystems, ingestion dose assessments, food countermeasures

Ulla Koskelainen, BSc (Biology), Assistant Researcher
Gamma spectrometric analysis, databases and data analysis

4.4 Radionuclide Analytics

The Laboratory for Radionuclide Analysis was founded in 2007 by merging the laboratory nuclide analyses from several units (Radioecology, Natural Radiation, Radiation Hygiene) into one laboratory.

4.4.1 Key words and specific technologies

Monitoring of radionuclides in the environment of nuclear power plants and the Baltic Sea, measurement services, development of analytical methods used in the laboratory (alpha, beta and gamma), laboratory information management system (LIMS), natural radioactivity in drinking water and treatment methods, quality assurance, metrology, co-ordination of laboratory work in emergency preparedness and radiochemistry.

Specific technologies relate to extensive know-how in gamma spectrometry, especially in low-level measurements, beta spectrometry and alpha spectrometry, liquid scintillation counting, radiochemical methods for ^{3}H, ^{14}C, $^{89,90}Sr$, $^{239,240}Pu$, ^{241}Am, ^{244}Cm ^{222}Rn, ^{234}U, ^{235}U, ^{238}U, ^{210}Pb, ^{226}Ra, ^{210}Po, gross alpha and beta measurements and environmental sampling methods, especially aquatic sampling.

4.4.2 Description of laboratory activities

The main function of the Laboratory is to provide analytical services for other units in STUK as well as external customers. The Laboratory also participates in research projects. For example, it has participated in several international research projects financed in part by Nordic Nuclear Safety Research (NKS) and by the EC:

- 2009–2010 Partner in the NSK project “Nordic seminar for users of gamma spectrometry (Gammasem)”
- 2008–2011 Partner in the EU project “Security and decontamination of drinking water distribution systems following a deliberate contamination (SecurEau)”
- 2006–2008 Partner in the EU project “A Future for Radioecology in Europe (FUTURAE)”
- 2004–2005 Short-term experts in the EU Phare consultation project to increase the credibility and improve the working practices of the RDC (Latvia) through the implementation of QA/QC (EC)

In addition, the Laboratory has contributed to the development of radiochemical and sampling methods. High-level research is based on results of qualitative and accurate radioactivity measurements. In the future, the need for low-level radioactivity measurements will increase and raises requirements for research infrastructure and quality management in the Laboratory.

In methods development, attention has been paid to the analysis of natural radionuclides due to the expansion of the mining industry. Analysis methods examined in radiochemistry have included liquid extraction for ^{210}Po, determination of ^{210}Pb using extraction chromatography, comparison of analytical methods used to determine uranium and lead by alpha, beta and gamma spectrometry, and rapid alpha analysis using direct alpha measurement. In addition, the Laboratory has tested rapid methods for emergency preparedness.

In gamma spectrometry, a new analysis tool, UniSampo Shaman (USS) software for gamma analyses, has been adopted. A new comprehensive database (Linssi) has also been taken in use. Optimal sample amounts and uncertainty estimates in sampling have been a continuous line of research and development. The Laboratory is also responsible for knowledge of treatment methods for removing natural radionuclides from drinking water.

Expert services

One of the main tasks of the Laboratory for Radionuclide Analysis is to provide laboratory analyses for research projects. This is done in co-operation with other research units at STUK. Laboratory services are provided for all kinds of environmental samples (e.g. air samples, sediments, soil, mushrooms, berries, lichen, moss, aquatic plants), foodstuffs, wipe samples, building materials, industrial products, drinking water samples and bioassay samples (urine). In addition, the Laboratory provides analysis services for external customers.

The Laboratory is responsible for a radiation monitoring programme in the vicinities of the Finnish nuclear power plants. The Laboratory carries out the work as a contracted service to the power plants. The environmental monitoring programmes of the Finnish nuclear power plants at Loviisa and Olkiluoto are relatively extensive, altogether including about 1 000 samples/analyses per year. The Radionuclide Analysis Laboratory is responsible not only for laboratory work, but also for most of the sampling linked with the monitoring. Every four years, contract negotiations are held with nuclear power plants associated with the monitoring programme and the Laboratory then participates in designing the monitoring programme based on previous monitoring experience. The extensive environmental data produced as a result of the routine monitoring programmes are valuable and have also been used as sources of information for more comprehensive scientific studies.

In addition, the Laboratory provides laboratory services and sampling to two other permanent monitoring programmes: the national environmental surveillance programme and monitoring of radioactive substances in the Baltic Sea in co-operation between all the Baltic Sea countries (Helcom-MORS).

The analyses provided include gamma spectrometric analysis, radio chemical analysis using liquid scintillation counters, proportional counters or alpha spectrometry, and environmental sampling. Altogether, the Laboratory conducted 2 228 gamma spectrometric analyses, 533 radiochemical analyses and 451 environmental samplings in 2010.

Development and maintenance of quality system

The quality system is the basis for high quality laboratory work and thus for high-level research. One of the key issues for the Laboratory is development of the quality management system used in the Laboratory and the Department of Research and Environmental Surveillance. The main parts of accredited analysis are carried out in the Laboratory for Radionuclide Analysis.

Metrology

The Departement of Research and Environmental Surveillance is responsible for the maintenance of the national standards for activity and activity concentrations. At the department these are maintained in the Laboratory for Radionuclide Analysis.

The goal of the national metrological activities is to provide accurate and internationally comparable radiation measurements. In order to achieve this, the Laboratory maintains measurement standards to ensure the reliability of activity measurements. The standards are accurate spectrometers or other equipment used for radiation measurement with traceable calibration, validated methods, or certified radioactive sources. To ensure our national standards, the Laboratory actively participates in international intercomparisons. The metrology activities include the following:

- extension of gamma spectrometric measurement for low energies, for example 46 keV (Pb-210)
- a new analysis tool (USS) and Monte-Carlo calculations for efficiency determination in gamma spectrometry
- development of uncertainty estimations in gamma spectrometry
- participation in an ICRM working group
- maintenance of a radionuclide register for certified radionuclide solutions and sealed sources
- certified alpha and beta activity solutions are used in the calibration of measuring devices
- participation in the certification of reference material with other national metrology laboratories
- regular participation in intercomparison measurements (IAEA/ALMERA, CTBTO, PROCORAD, Helcom-MORS and other national projects).

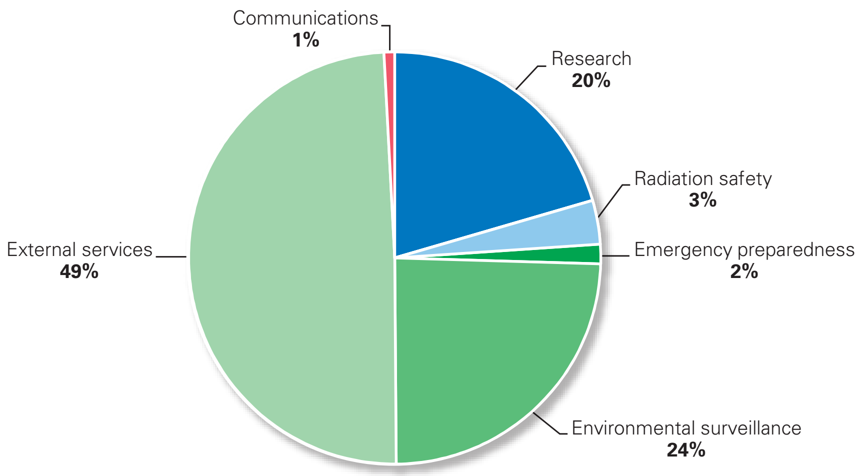
STUK is a member in the ALMERA network (Analytical Laboratories Measuring Environmental Radioactivity). STUK also participates in the activities of ICRM (International Committee for Radionuclide Metrology) and its Gamma-Ray Spectrometry Working Group Intercomparison of methods for coincidence summing corrections in gamma-ray spectrometry. One of the goals is to become a permanent member of ICRM.

Standardisation

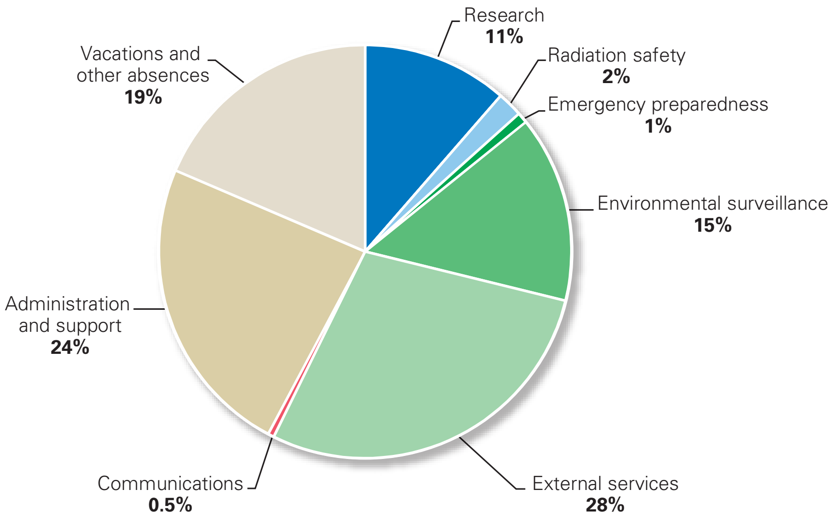
The Laboratory has participated in the standardisation work of the Technical Committee TC147: Water quality, radiological measurements (WG4), by commenting and voting on draft ISO standards for the National Committee.

Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures.

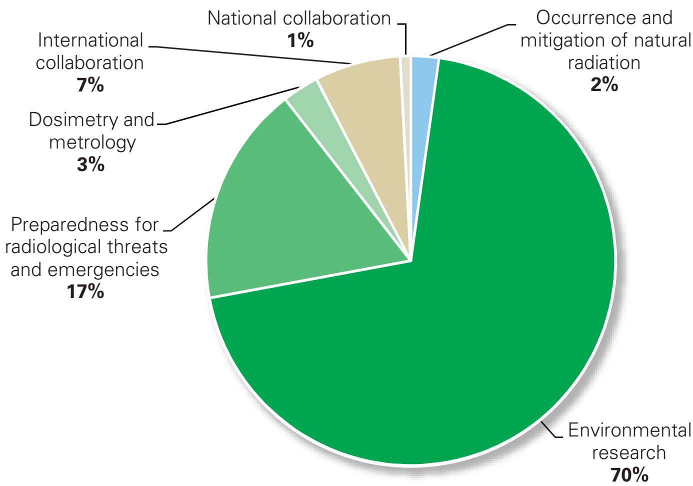
Total costs 1 425 k€ distributed by sectors in 2010



Effective working time by sectors in 2010
Total person-years 13.1



Effective working time of research by areas in 2010
Total person-years 1.5



4.4.3 Personnel

The personnel in the Radionuclide Analytics Laboratory at the end of 2010 are listed below.

Pia Vesterbacka, PhD (radiochemistry), Head of Laboratory
Measurement services, radiochemistry, natural radioactivity in household water, treatment methods, quality management, laboratory work in emergency preparedness, measurement standards

Seppo Klemola, MSc (Physics), Senior Scientist
Development of gamma-ray spectrometry, CTBT laboratory analyses (deputy), airborne radioactivity, environmental monitoring of nuclear power plants, quality assurance, measurement standards

Vesa-Pekka Vartti, MSc (Radiochemistry), Scientist
Complex gamma spectrum analyses, environmental monitoring of nuclear power plants, radiochemistry, radiochemical nuclide analytical methods, including alpha and beta spectrometry, quality assurance

Kaisa Vaaramaa, PhD (Radiochemistry), Scientist
Terrestrial radioecology, radiochemistry, radiochemical nuclide analytical methods, including alpha and beta spectrometry, quality assurance

Tarja Heikkinen, MSc (Radiochemistry), Assistant Researcher
Radiochemical nuclide analytical methods, including alpha and beta spectrometry, bioassay methods, quality assurance

Antti Vainonen, MSc (Information Technology), Systems Specialist
Laboratory information management system (LIMS)

Kari Huusela, Research Technician
Environmental sampling and field studies, gamma spectrometric measurements

Marjaana Ahonen, Research Assistant
Pre-treatment of samples and radiochemical analyses

Eija Haakana, Research Assistant
Pre-treatment of samples and radiochemical analyses

Aimo Kemppainen, Research Assistant
Pre-treatment of samples and radiochemical analyses, gamma spectrometric measurements

Reko Simola, Research Assistant
Pre-treatment of samples and radiochemical analyses, gamma spectrometric measurements

Ulla Yli-Arvo, Research Assistant
Pre-treatment of samples and radiochemical analyses

Tuula Korttinen, Laboratory Operator
Reception and pre-treatment of samples

Ulla Välikangas, Laboratory Operator
Pre-treatment of samples, gamma spectrometric measurements

4.5 Environmental Surveillance and Preparedness

The Environmental Surveillance and Preparedness Laboratory was formed in 2007 by splitting the previous Laboratory for Airborne Radioactivity into two parts, one carrying out operational monitoring and preparedness tasks and the other focusing on research (Security Technology).

4.5.1 Key words and specific technologies

Surveillance of environmental radioactivity, airborne radioactive material, external dose rate monitoring, regional laboratories, atmospheric transport, dose estimation, emergency preparedness, environmental modelling, countermeasures, nuclear emergency management, decision support

Computer codes for atmospheric dispersion of radioactive substances and radiation doses to man, nationwide external dose rate monitoring and information system, nationwide surveillance of airborne radioactive material, gamma spectrometry, decision support systems for nuclear emergency management (RODOS system), GIS, collaborative software for emergency preparedness and response (KETALE).

4.5.2 Description of laboratory activities

The responsibilities of the Environmental Surveillance and Preparedness Laboratory are:

- surveillance of environmental radioactivity (external dose rate, airborne radioactive substances, radionuclides in deposition, radioactivity in drinking water and surface water, radioactive substances in milk, foodstuffs and wastewater sludge)
- expert services especially in the area of the CTBT (Comprehensive Nuclear-Test-Ban Treaty)
- improvement of nuclear emergency management and decision support
- development of collaborative software for emergency preparedness and response (KETALE system)
- improvement of environmental monitoring systems for radioactivity
- coordination and support of regional laboratories
- provision of expert services on emergency planning and preparedness.

Environmental radiation monitoring programme

The Laboratory is responsible for the surveillance of environmental radioactivity. Other laboratories in the research department contribute to and take part in this surveillance programme. Measurements and radiochemical analyses are performed in the Radionuclide Analysis Laboratory. The Regional Laboratory in

Northern Finland carries out surveillance of airborne radioactivity in Northern Finland, and radioactivity in people is monitored by the Environmental Research Laboratory. Surveillance of the total beta activity in air is carried out by the Finnish Meteorological Institute (FMI).

The Laboratory operates a nationwide real-time dose rate monitoring network consisting of 255 stations. Ambient dose rate readings are presented to other authorities by means of the USVA system. This system is a web portal that the Laboratory has developed especially for this purpose and is continuously updated. Monitoring results are also presented on STUK's public web site.

Dose rate monitoring stations around the Finnish nuclear power plants are equipped with $LaBr_3$ spectrometers. These spectrometers operate with the same 10-minute measuring interval as at normal dose rate monitoring stations. However, the spectrometers have a 20–50 times lower detection limit compared to normal monitoring stations equipped with a GM detector. It is possible to identify from the spectrum which nuclide or nuclides are responsible for elevated radiation levels.

Airborne radioactivity is monitored by eight sampling stations. Most of the samplers are manually operated; however, there is a fully automated station on the roof of the STUK building in Helsinki. The filters are measured with a high-resolution gamma spectrometer and the results of the analysed spectrum are presented on STUK's internal web pages.

The sampling in other parts of the monitoring programme is conducted in cooperation with other authorities and companies. Partners collect samples and send them to STUK, where they are prepared, analysed and reported. These results are also reported once in a year to the European Union.

Emergency preparedness

The Laboratory has, in cooperation with the Finnish Meteorological Institute, created the KETALE collaborative software, which has an important role in STUK's emergency preparedness and response. KETALE integrates distributed modelling expertise (weather forecasts and dispersion predictions by FMI, source term and dose assessments by STUK) and facilitates collaboration and the sharing of information. The system helps the various groups to produce reports on the radiological situation or provide countermeasure recommendations. The system can be used to request, for example, dispersion and dose assessments from FMI and to present the results on an interactive map for easy comparison with measurements or with other assessments. All content can be easily added to reports, which can be viewed on-line, printed, or exported and imported into other systems.

The Laboratory maintains and operates the RODOS decision support system. The RODOS system received a major version upgrade a few years ago, and it required work to implement it into STUK's emergency procedures. Continuous prognostic dispersion assessments for fictitious releases from any of the two domestic NPP sites are made hourly on a 24/7 basis and the results are displayed in STUK's emergency centre. The purpose of the setup is to provide users with a constantly updated view of the current dispersion situation around our domestic NPP sites.

The long-term goal of the Laboratory is to shield model users from the intricacies of yet another user interface and to relieve them from the burden of installing software. The Laboratory tries to provide access to model services through the KETALE system, which needs only a Web browser for user interaction. The RODOS system was interfaced with the KETALE system in this sense.

The Laboratory created simulation software for measurement data from the measurement stations. This is an example of the constant drive of the Laboratory to make exercises as realistic as possible.

STUK has provided gamma spectrometric measuring devices to local environmental health care laboratories. The Laboratory provides training and support in normal situations and coordinates their activity in an emergency situation.

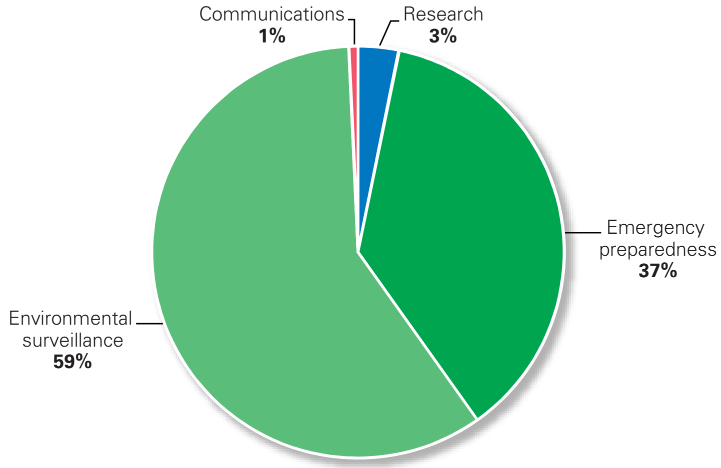
The Laboratory cooperates closely with the Finnish Meteorological Institute, FMI (atmospheric transport and dispersion), the Ministry of the Interior (external dose rate monitoring) and the Finnish Defence Forces (air sampling and fallout mapping using aerial vehicles).

Services

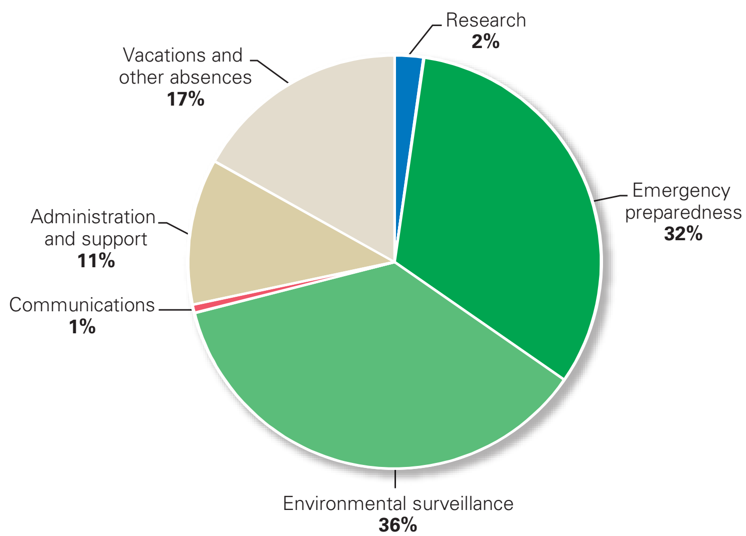
STUK is one of the IMS (International Monitoring System) radionuclide laboratories for the verification of the CTBT. The Laboratory provides routine services for the CTBTO on a service-for-fee basis. The Laboratory provided expertise on various occasions to the IAEA and was part of a consortium that installed the RODOS software in various countries (Bulgaria, Croatia, Czech Republic, and Slovenia).

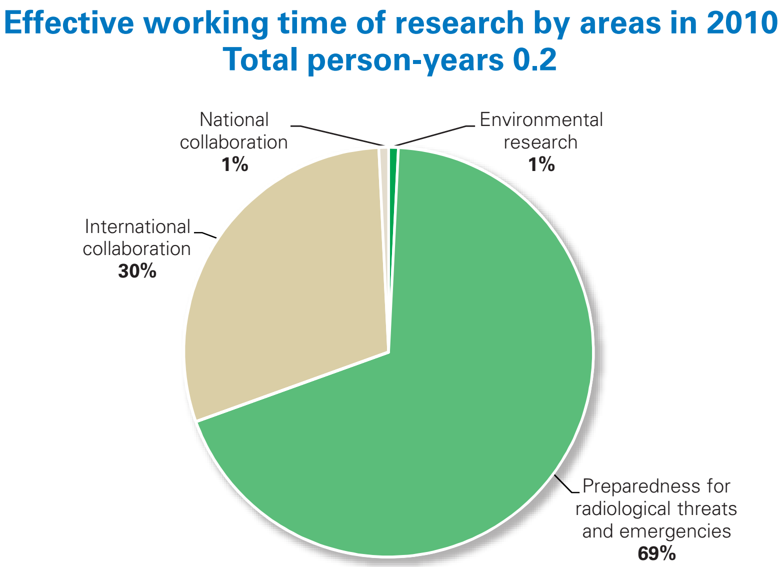
Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures. They show that research and technological development form a relatively small part of the Laboratory's operation.

Total costs 1 180 k€ distributed by sectors in 2010



Effective working time by sectors in 2010
Total person-years 9.5





4.5.3 Personnel

The personnel in the Environmental Surveillance and Preparedness Laboratory at the end of 2010 are listed below.

Kaj Vesterbacka, MSc (Physics), Head of Laboratory
Management, external dose rate monitoring, emergency planning and preparedness

Juhani Lahtinen, MSc (Engineering), Senior Scientist
Atmospheric dispersion and dose calculations, radiation monitoring, analysis of radiation threats, emergency preparedness

Michael Ammann, MSc (Engineering), Senior Scientist
Decision support systems for nuclear emergency management, environmental modelling, development of the KETALE system, emergency preparedness

Aleksi Mattila, PhD (Physics), Senior Inspector
Development of a data management system for gamma spectrometry, CTBTO services, complex gamma spectrometric analysis

Mikko Leppänen, (Engineering), Inspector
Maintenance of the nationwide external dose rate monitoring network, coordination and support for the local laboratories.

Tuomas Peltonen, MSc (Chemistry), Inspector
Development of the KETALE system, decision support systems for nuclear emergency management, emergency preparedness

Santtu Salmelin, (Engineering), Inspector
Maintenance of the nationwide external dose rate monitoring network, coordination and support for the local laboratories.

Ulla-Maija Hanste, (Radiochemistry), Assistant Inspector
Coordination and support for the local and regional laboratories, monitoring of radioactivity in the environment, coordination and support for the local laboratories.

Riitta Kontro, (Engineering), Assistant Inspector
Maintenance of the network of air samplers, data management, gamma spectrometric analysis of air filters.

4.6 Security Technology

The Laboratory of Security Technology was established in 2007 when the former Laboratory for Airborne Radioactivity was split into two parts. The nationwide radiation monitoring was assigned a laboratory of its own, whereas responsibility for research into measurement technology was given to another laboratory taking into account the new and fast growing needs in nuclear security.

4.6.1 Key words and specific technologies

Novel technologies, radiation measurements, nuclear security, safeguards, mobile measurements, reachback, radioactive particle analysis, emergency preparedness. Novel radiation measurement techniques, event-mode data acquisition, coincidences, analyses of individual radioactive particles, databases, software for spectrum analysis, mobile laboratory and backpack for environmental monitoring

4.6.2 Description of laboratory activities

The responsibilities of the Laboratory are:

- Research on radiation measurement technology for emergency preparedness, safety, security and safeguards
- Research and development of novel analysis software
- Development and maintenance of tools for mobile in-field measurements
- Expert services
- Radioactive waste.

Nuclear Security

The Laboratory cooperates closely with the Finnish police, customs and other government organisations to prevent criminal or unauthorised acts involving nuclear or other radioactive materials. This cooperation has led to the in-field capability of first-line officers to perform high-quality spectroscopy. The field teams save the results in a remote database for expert review in real time. Through this capability the Finnish authorities have an excellent response capability against radiological and nuclear threats, incidents and accidents.

Research

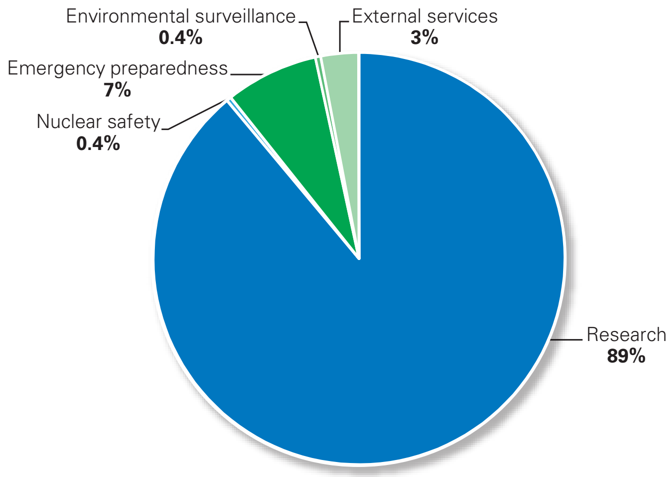
The research carried out at the Laboratory supports nuclear security and emergency preparedness. Methods on event-mode data acquisition and other coincidence measurement systems are the major R&D target. Other striking results have been achieved in the development of software for gamma and alpha spectrometry. The Laboratory co-operates with several Finnish universities and foreign research institutions.

Services

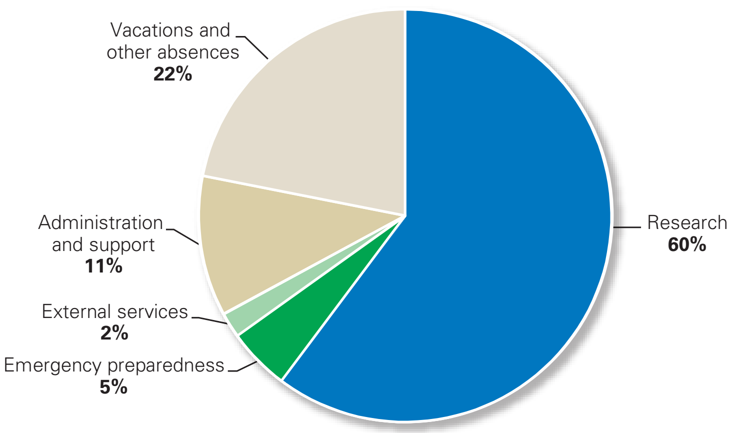
The Laboratory provides environmental spectroscopy services. In particular, in-situ spectroscopy is regularly performed near the Finnish nuclear installations. Other environmental missions are also performed, such as the screening of sites for possible uranium mining before industrial activity takes place.

Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures.

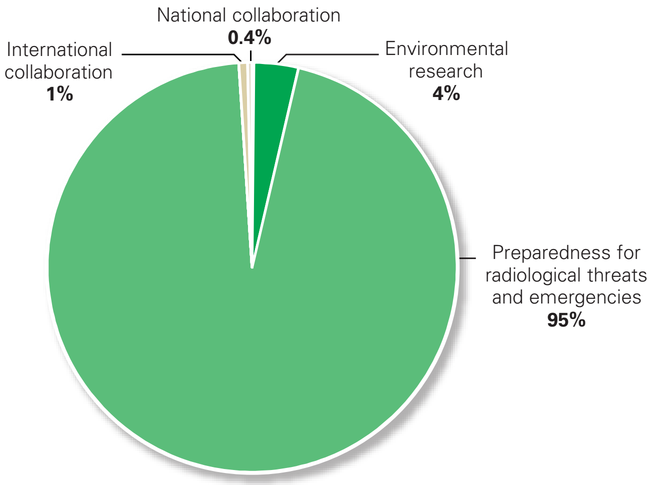
Total costs 1 293 k€ distributed by sectors in 2010



Effective working time by sectors in 2010
Total person-years 10.2



Effective working time of research by areas in 2010
Total person-years 6.1



4.6.3 Personnel

At the end of 2010, there were altogether 10 permanent and fixed-term posts in the Laboratory of Security Technology:

Harri Toivonen, DTech (Nuclear Physics), Head of Laboratory
Radiation measurements, radiation and nuclear threats, nuclear security, safeguards

Kari Peräjärvi, PhD, Docent of Nuclear Physics, Senior Scientist
Radiation measurements, analysis of radiation threats, emergency preparedness

Roy Pöllänen, PhD (Physics), Senior Scientist
Airborne radioactive particles, particle analysis techniques, aerosol physics, dose calculations, direct alpha spectrometry

Tarja Ilander, Systems Specialist
Development of tools for nuclear security, emergency preparedness, system design, database administrator

Ari-Pekka Sihvonen, MSc (Physics), Scientist
Simulations, neutron measurement technology

Petri Smolander, MSc student (Physics), Scientist
Mobile radiation measurements, radioactive waste, education

Jani Turunen, MSc (Physics), Scientist, PhD student
Novel measurement technologies, data acquisition

Sakari Ihantola, MSc (Physics), Scientist, PhD student
Novel measurement technologies, spectrum analysis

Tero Karhunen, MSc student (Mathematics), Scientist
In-field gamma spectrometric data acquisition and analysis software

Samu Ristkari, MSc student (Information Technology), Systems Specialist
Tools for data management, programming

4.7 Regional Laboratory in Northern Finland

The Regional Laboratory in Northern Finland is the only laboratory of STUK outside the Helsinki headquarters. The Laboratory was established in 1970 for the follow-up of radioactivity in the environment after the atmospheric nuclear tests.

4.7.1 Key words and specific technologies

Environmental radioactivity research and monitoring, terrestrial radioecology, Arctic and sub-Arctic food chains, lichen, reindeer, radioactivity in Arctic sea areas, radioactivity related to mining activities

Gamma spectrometry, alpha spectrometry, radiochemical methods, environmental sampling methods, portable radiation counters and spectrometers

4.7.2 Description of laboratory activities

The Regional Laboratory in Northern Finland is located in the heart of Finnish Lapland in Rovaniemi on the Arctic Circle. The Laboratory has had new facilities at the Finnish Geological Survey since March 2010. It is the most northern laboratory in the European Union, performing radioactivity analysis and monitoring of the environment. The Laboratory participates in the Arctic Monitoring and Assessment Programme (AMAP). Research at the Regional Laboratory in Northern Finland focuses on northern radioecology. This includes studies in the mining and milling environment, environmental samples, the northern food chains and foodstuffs produced in the Finnish provinces of Lappi and Oulu. In addition, it is one of the regional laboratories designated in the national emergency preparedness plans. The Laboratory participates in the national radiation monitoring programme and research projects in the Arctic and sub-Arctic. The Regional Laboratory in Northern Finland also offers radiation measurement services to customers. Several analysis methods have been accredited by the Finnish Accreditation Service (FINAS) according to the ISO 17025 laboratory standard.

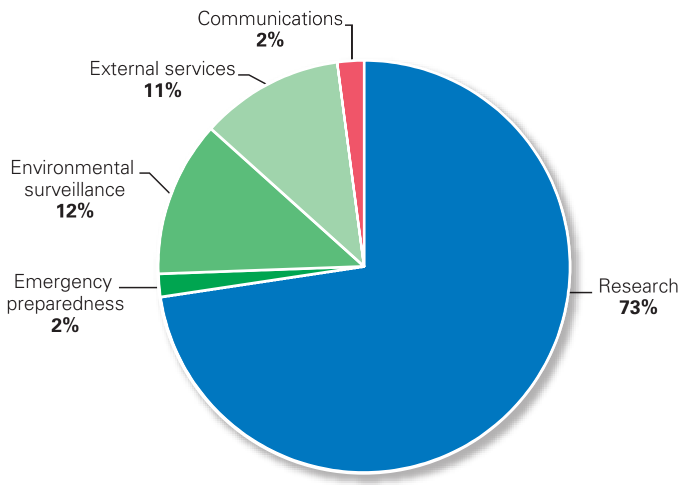
The objective of radioecological studies is to determine how radioisotopes are transported and accumulated in the sub-Arctic and Arctic food chains and the environment. The Regional Laboratory in Northern Finland has conducted radioactivity studies of locally produced foodstuffs, game, natural foodstuffs, and environmental studies for over 40 years. Thus, valuable information has been obtained on the accumulation of radioisotopes in food chains important to man. Due to the special features of the northern regions, the radioisotopes are transported and accumulated in the food chains very efficiently, e.g. the food chain lichen-reindeer-man. The research has been conducted on both natural and anthropogenic radioisotopes. Recent projects include a study on the mobilisation of radionuclides from mining mill tailings, cosmogenic isotopes as atmospheric tracers (Be-7 and Na-22) and radiological baseline studies in the Sokli area and Talvivaara mine.

The Laboratory collaborates closely with universities and local organisations. Participation in international research projects with research institutes from the European Union, Nordic countries and from the Barents region has created a strong co-operative network. An EU funded research project CEEPRA was recently started to establish a cooperation network in the EuroArctic region.

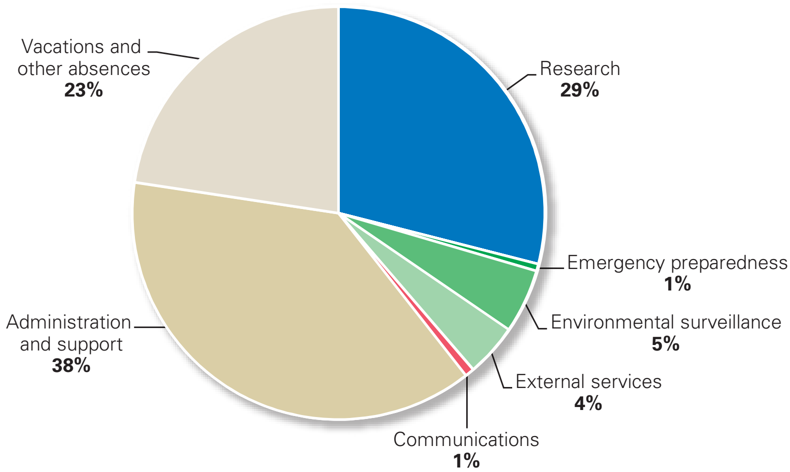
The Laboratory participates in the national surveillance programme for environmental radiation. The monitoring programme consists of an automated external radiation monitoring network, periodical monitoring of deposition and airborne radioactive substances in Rovaniemi, Sodankylä and Ivalo in Lapland and periodical monitoring of foodstuffs produced in the area. In case of a nuclear or radiological emergency, the Laboratory is strongly connected to STUK's emergency response organisation, especially by providing expertise concerning the special conditions of the northern environment. During emergencies the Laboratory is also responsible for radioactivity measurements in Northern Finland. The Laboratory regularly takes part in national and international emergency exercises.

Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures.

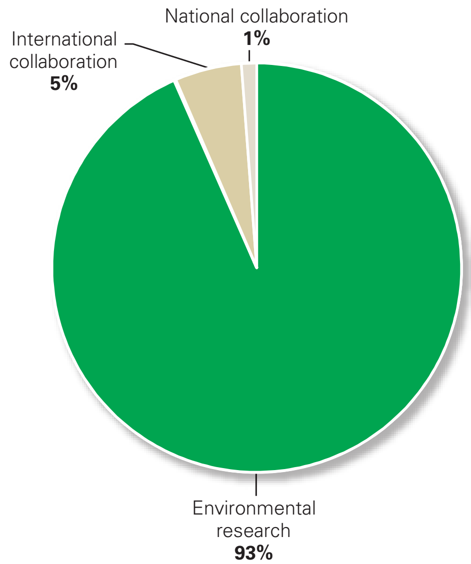
Total costs 950 k€ distributed by sectors in 2010



Effective working time by sectors in 2010
Total person-years 9.1



Effective working time of research by areas in 2010
Total person-years 2.6



4.7.3 Personnel

At the end of 2010, there were altogether eight permanent positions in the Regional Laboratory in Northern Finland:

Dina Solatie, PhD (Radiochemistry), Head of Laboratory
Management, terrestrial radioecology, radiochemistry, uranium mining and milling, quality assurance

Ari-Pekka Leppänen, PhD (Physics), Senior Scientist
Gamma spectrometry, airborne radioactivity monitoring and research, close-region collaboration, Arctic radioactivity research, field measurements

Maarit Risto, PhD (Chemistry), Scientist
CEEPRA project administration, radioecology, chemistry, research, immediate superior

Jarkko Ylipieti, BSc (Land surveyor and computer science and information engineer) Scientist
Collecting, processing, presenting and using spatial and geographical data in digital form (Geomatics), use of Geographical Information Systems, data analysis from the results of radiological measurements, RODOS user

Hannele Koukkula, Research Assistant
Pre-treatment of samples, sampling, radiochemical Pu analysis and gamma measurements

Eeva Hakamaa, Laboratory Operator
Pre-treatment of samples, radiochemical plutonium and polonium analysis

Tuula Virtanen, Laboratory Operator
Pre-treatment of samples, surveillance of environmental radiation in Lapland (deposition), secretarial duties

Aila Iivari, Assistant
Secretarial duties

4.8 Radiation Biology

The Radiation Biology Laboratory was established in 1984 by expanding the previous medical research group established in 1975. Over the years, the size of the Laboratory has varied considerably, depending on the number of fixed-term personnel. No essential changes to the functions of the Laboratory were made in the latest organisational change in 2007.

4.8.1 Key words and specific technologies

Radiation biology, molecular biology, molecular cytogenetics, biodosimetry, proteomics, health effects, ionising radiation, X-ray and γ-ray irradiation, microbeam irradiation, narrow/broad beam α-particle irradiation, non-ionising radiation, RF-EMF, mobile phones, radiation-induced cancer, hereditary effects, non-targeted effects of ionising radiation, chromosomal aberrations, individual susceptibility, individual radiation sensitivity, minisatellites, mutations, single nucleotide polymorphisms (SNPs), proteome-wide protein expression changes, endothelial biology, cellular stress response, cytoskeleton, apoptosis, blood-brain-barrier, ultraviolet radiation, UVA, UVB, solarium radiation

Difference Gel Electrophoresis (DIGE), DeCyder/PDQuest protein expression pattern analysis, mass spectrometry protein identification (Maldi-ToF), protein activation (phosphorylation) assay, immunohistochemistry, Western blotting, FISH chromosome painting, PCC (premature chromosome condensation) assay, micronucleus assay, apoptosis assays, viability assay, gap-junction function, artificial human tissue systems, primary human skin biopsies.

4.8.2 Description of laboratory activities

The responsibilities of the Radiation Biology Laboratory are:

- research on the biological and health effects induced by ionising and non-ionising radiation,
- biological dose assessment by chromosomal analysis,
- biological expertise for assessment of the medical consequences of radiation exposure.

Research

Research projects conducted at the Radiation Biology Laboratory examine biological effects induced by ionising or non-ionising radiation on living matter (cells, tissues, animals, humans).

During 2005–2010, the topics covering the biological effects of low dose ionising radiation were:
1. individual susceptibility (Cleanup workers' CA, ATModelDirect)
2. non-targeted effects of ionising radiation (NOTE, DoReMi)
3. non-cancer effects (CARDIORISK)

In addition, studies on biological dosimetry have been conducted (BIONCA, BIODOS, BIOPEX, MULTIBIODOSE, CA follow-up, RT case-study, Dicentric calibration curve).

During 2005–2010, topics covering the biological effects of non-ionising radiation were:
1. Effects of mobile phone radiation (RF-EMF) on human skin *in vivo*
2. Effects of RF-EMF on human sperm *ex vivo*
3. Effects of RF-EMF on human endothelial cells *in vitro*
4. Effects of RF-EMF on C. elegans in vivo
5. Effects of long-wave ultraviolet radiation (UVA) on melanoma cells *in vitro*
6. Effects of UVA radiation on melanoma metastasis in a mouse model.

In addition, individual susceptibility in the aetiology of brain tumours was investigated (INTERPHONE).

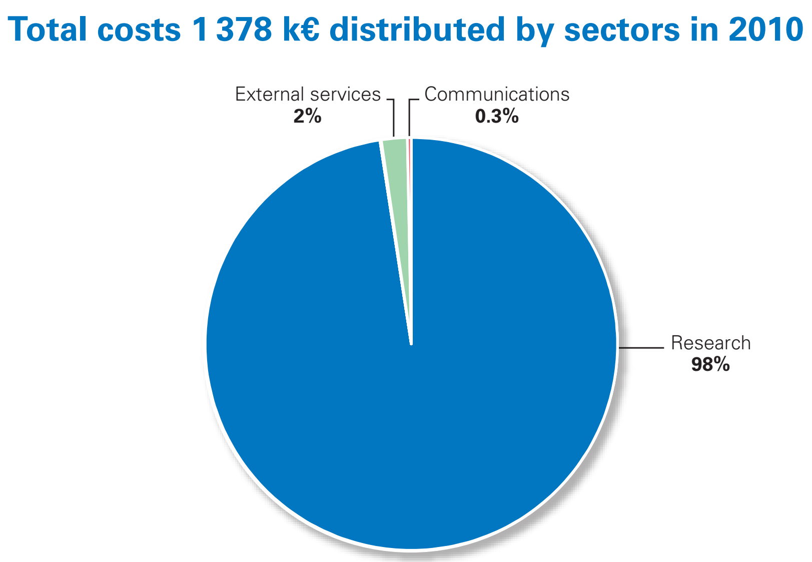
The Laboratory actively participates in national and international research programmes and is collaborating with research institutes in Europe, the USA, China and South Africa. Funding for research projects comes from both national funding agencies (Ministry of Social Affairs and Health, Academy of Finland, National Technology Agency, Finnish Cancer Society, Emil Aaltonen Foundation, Finnish Work Environment Fund) and international funding agencies (EU 6th and 7th Framework Programmes, Nordic Cancer Union, Nordic Nuclear Safety Research).

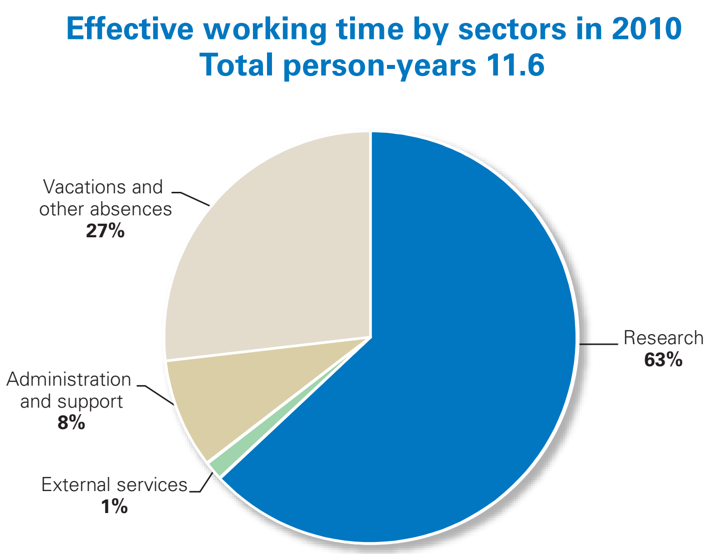
Collaboration with other laboratories in STUK is a prerequisite for the research. In the field of ionising radiation, the Radiation Metrology Laboratory provides dosimetry and irradiation services as well as developing irradiator systems for biological samples. Technical expertise for exposure settings for mobile phone radiation is obtained from the unit of Non-Ionizing Radiation Surveillance. Cooperation with the Laboratory of Health Risks and Radon Safety is significant in assessing and investigating exposed cohorts of interest, as well as providing statistical expertise for data analysis.

Expert services

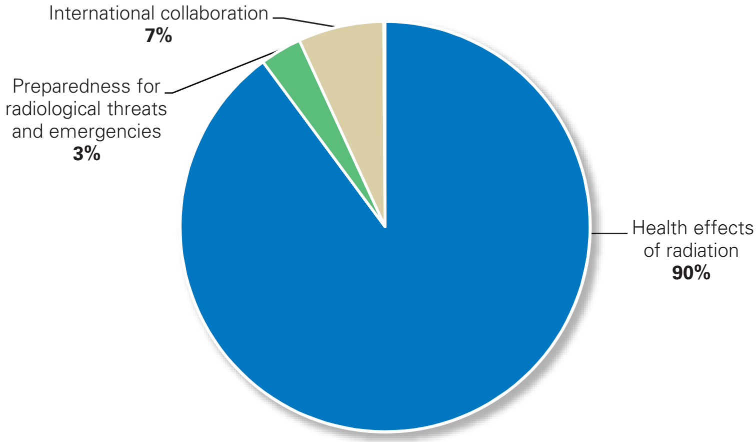
Biological dose assessment by analysis of dicentric chromosomes is performed in cases of suspected over-exposure to ionising radiation. The dose assessment method is accredited.

Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures.





Effective working time of research by areas in 2010
Total person-years 7.3



4.8.3 Personnel

At the end of 2010, there were a total of eleven permanent positions in the Radiation Biology Laboratory:

Virpi Launonen, PhD, Docent (Molecular Genetics), Head of Laboratory (2007–)
Laboratory management, genetic susceptibility, biological effects of ionising radiation, individual radiation sensitivity, radiation-induced cancer, non-targeted effects of radiation

Dariusz Leszczynski, PhD, DSc, Docent (Molecular Biology & Biochemistry), Research Professor (2000–) and Head of Laboratory (2003–2007)
Genome-wide and proteome-wide screening of cell response to non-ionising radiation (in 2005 also ionising radiation), cellular stress response, cytoskeleton, signalling pathways

Carita Lindholm, PhD (Genetics), Senior Scientist
Molecular cytogenetics, biological effects of ionising radiation, biodosimetry (including retrospective dosimetry), genetic susceptibility, individual radiation sensitivity, non-targeted effects of radiation, emergency preparedness

Anne Kiuru, PhLic (Genetics), Scientist, Doctoral student
Molecular biology, molecular cytogenetics, hereditary effects of radiation, mutation analysis, individual radiation sensitivity, genetic susceptibility, non-targeted effects of radiation, emergency preparedness

Meerit Kämäräinen, PhD (Cell and Molecular Biology), Scientist (2008–)
Cell biology, molecular biology, biological effects of ionising radiation, non-targeted effects of radiation

Elina Lemola, MSc (Biotechnology), Scientist (2010–)
Proteomics, cell biology, molecular biology

Reetta Nylund, MSc (Tech.) (Biophysics), Scientist, Doctoral student
Proteomics, protein expression, molecular biology, cell biology, biological effects of ionising and non-ionising radiation

Armi Koivistoinen, MSc (Genetics), Assistant Researcher
Molecular cytogenetics, chromosome aberrations, FISH chromosome painting

Marjo Perälä, BSc Engineer (Food Processing), Laboratory Engineer
Molecular biology, biological effects of ionising radiation, non-targeted effects of radiation

Pia Kontturi, Laboratory Operator
Cell culture, SDS-PAGE gel electrophoresis, immunohistochemistry, histology

Marja Huuskonen, Laboratory Technician
DNA extraction, protein extraction, SDS-PAGE gel electrophoresis, cell culture

4.9 Radiation Practices Regulation

Radiation Practices Regulation is the department of STUK that is responsible for the supervision, licensing and regulation of the use of radiation. In addition, the department undertakes research in the fields of the use of radiation and dosimetry and metrology, maintains the national measurement standards for dose quantities of ionising radiation, gives education and training and provides expert services. The overall coordination of metrology at STUK is carried out by a person from the Radiation Metrology Laboratory.

4.9.1 Key words and specific technologies

Medical use of radiation, radiation dosimetry, diagnostic X-ray imaging, radiation therapy, nuclear medicine, industrial use of radiation, radiation protection, patient dose, image quality, radiation risk, radiation metrology, standard dosimetry, calibration techniques, occupational dose monitoring, X-ray spectrometry, Monte Carlo calculation methods, surveys on medical use of radiation, surveys on personal dose monitoring.

4.9.2 Description of the activities

Regulatory activities

The use of ionising radiation in Finland requires a safety licence under section 16 of the Radiation Act. Applications for such a licence must be submitted in writing to STUK. A safety licence will be granted when the purpose of use of radiation, the methods employed, the radiation sources and equipment, the premises of use and radiation shielding, the safety systems, the user's organisation and the safety guidance comply with the statutory safety standard, as further described in the Radiation Safety (ST) Guides. ST Guides are published by STUK.

STUK may exempt other types of use of radiation from safety licensing if it is possible to ascertain with sufficient reliability that the use of radiation will cause no detriment or danger to health. Licence-exempt use of radiation may be ordered to be notifiable to STUK. Licence-exempt radiation devices may also be ordered to be notified for the purpose of registration, pursuant to section 20 of the Radiation Decree. The notification obligation and any other terms and conditions of exemption will be specified in the decision of exemption issued by STUK. Notifiable devices include conventional dental X-ray equipment. STUK maintains a register of licensees and medical devices producing ionising radiation and performs inspections on the use of radiation as stipulated in the Radiation Act 592/1991 (section 53).

Research

The research of the Department is aimed at improving knowledge and expertise in general, supporting the regulatory activities and to promoting the justified and optimised use of radiation. The research on radiation metrology is mainly related to maintenance of the national measurement standards for dose quantities of ionising radiation and development of measurement methods. In addition to publications and presentations, reliable dosimetry methods are also communicated to the users of radiation, for instance, during site visits.

Research on the medical use of radiation is often organised in joint projects of three units: X-ray in Health Care, Radiotherapy and Nuclear Medicine, as well as the Radiation Metrology Laboratory. This ensures that the best expertise available in the department is employed in the projects. The first two are regulatory units that, among other activities, make site visits to hospitals and also carry out research in collaboration with Finnish hospitals. The research on radiation metrology is mainly carried out by the staff of the Radiation Metrology Laboratory. The Management Support unit takes part in the harmonisation of occupational dose monitoring in Europe and verification of the quality of dosimetric services. The research on industrial uses of radiation is mostly conducted in the unit Radiation in Industry (a regulatory unit); however, there are some joint projects with the Radiation Metrology Laboratory. The overall coordination of the research at the Department of Radiation Practice Regulation is carried out by a person from the unit of Management Support who has been nominated as the "process owner" for research in the Department.

In addition to the internal research projects, research is also carried out in national and EU-funded research projects and in collaboration with other research organisations. In 2005–2010 we participated in five EU-funded research projects:

- Safety and efficacy for new techniques and imaging using new equipment to support European legislation (SENTINEL, 2005–2007)
- Increasing cancer treatment efficacy using 3D brachytherapy (EMRP J06, 2008–2011)
- External Beam Cancer Therapy (EMRP J07, 2008–2011)
- Non-targeted effects of ionising radiation (NOTE, 2006–2010)
- Low dose research towards multidisciplinary integration (DoReMi, 2010–2015)

Research-related co-operation also takes place with organisations such as the ICRU and IAEA, in their various working groups and report committees. In metrology, co-operation is carried out with other Nordic dosimetry laboratories and the EURAMET organisation (European Association of National Metrology

Institutes). In the field of medical use of radiation and individual dose monitoring, European projects are mainly performed under the umbrella of EURADOS (the European Radiation Dosimetry Group). In dosimetry, co-operation with Finnish universities (University of Jyväskylä, Åbo Akademi, University of Helsinki) and university hospitals has been established.

Education and training

The Department organises regular meetings and courses for radiological, technical X-ray and nuclear medicine personnel and for radiotherapy physicists. The courses on radiation protection and quality assurance for radiological personnel have been organised annually for 20 years and meetings for radiotherapy physicists for more than 25 years. In these meetings, reviews on current scientific topics are presented in addition to regulatory subjects.

The personnel of the department have participated in the following education and training activities:

- lectures and training in international (e.g., IAEA, EU) and national courses
- supervising doctoral theses and MSc theses (four doctoral theses, one Phil. Lic. thesis and four MSc theses in the period 2005–2010; these theses are included in the list of publications)

The experts in the department have participated in writing both national and international books on radiation protection and dosimetry.

Expert services

The department has provided expert services to the European Commission by coordinating an EC project (2007–2008) for the development of guidance on Clinical Audit, published as an EC report Radiation Protection 159. In 2010, the department started coordination of another EC project, Dose Datamed 2, a study on European population doses from medical exposure, for 2010–2012.

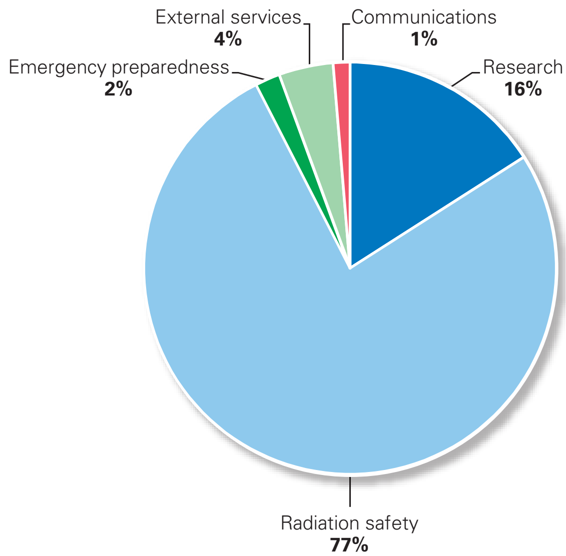
The department has carried out the EU Twinning project with Bulgaria. Outcomes in Bulgaria were updated calibration methods for the Bulgarian secondary standards dosimetry laboratory, updated regulatory control of modern radiotherapy and updated and established diagnostic reference levels in nuclear medicine and in diagnostic radiology. The department also participated in the EU Tacis Project with Belarus for transfer of knowledge and practices to the nuclear safety authorities of Belarus; the work by the department consisted of advisory support for the establishment of a calibration and testing laboratory for radiation protection dosimeters.

The Radiation Metrology Laboratory has provided calibration and testing services as a national standard dosimetry laboratory and other expert services.

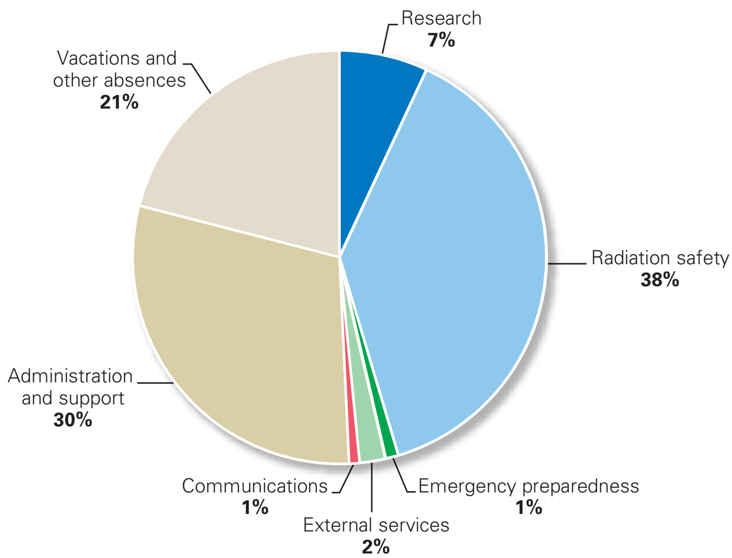
The services provided are:
- calibration and testing services for dosimeters used in radiation protection, diagnostic radiology and radiotherapy
- testing of diagnostic X-ray units in the laboratory and on-site
- developing, selling and providing user support for the PCXMC program
- calculation services, e.g. for estimating radiation shielding.

Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures. They show that the main activity of the Department is radiation safety regulation.

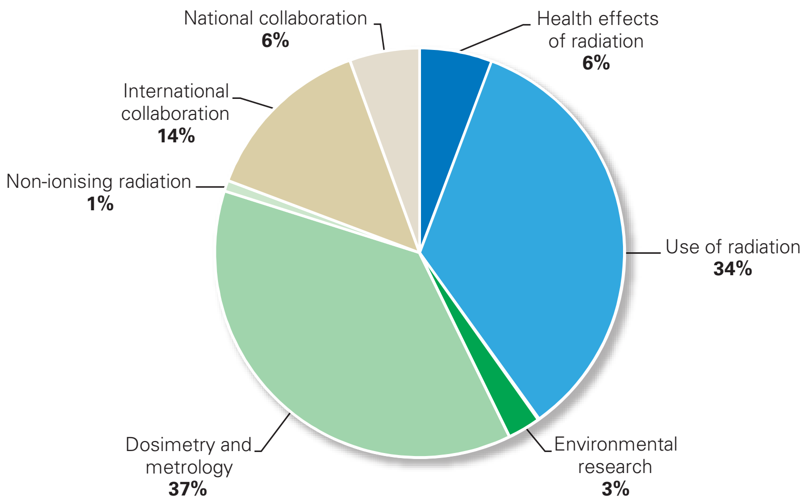
Total costs 4 681 k€ distributed by sectors in 2010



Effective working time by sectors in 2010
Total person-years 41.9



Effective working time of research by areas in 2010
Total person-years 2.9



4.9.3 Personnel

About half of the personnel in the Department participate in research. Their expertise areas are given below.

Hannu Järvinen, MSc (Engineering), Management Support, Principal Adviser
International co-operation, regulatory activities, research and development in medical use of radiation and in metrology

Radiation Metrology Laboratory

Antti Kosunen, Docent, PhD (Physics), Head of Laboratory
Radiation metrology, dosimetry, radiotherapy dosimetry, management, quality management

Arvi Hakanen, PhD (Physics), medical physicist, Senior Scientist
Research and development of dosimetry for radiation protection, standard and applied dosimetry, measurement and calibration techniques, quality assurance, calibration services

Teemu Siiskonen, PhD (Physics), Senior Scientist
Research and development of dosimetry, Monte Carlo methods, theory of dosimetry, spectrometry, radiation risk assessment, nuclear physics

Markku Tapiovaara, MSc (Physics), Senior Scientist
Research and development of X-ray dosimetry, theory of imaging physics, optimisation of imaging techniques, patient dose assessment, performance of X-ray units, expert services, standardisation

Ilkka Jokelainen, MSc (Physics), Senior Inspector
Standard dosimetry, measurement and calibration techniques, quality assurance, research and development of dosimetry for radiotherapy, calibration services, standardisation

Paula Toroi, PhD (Physics), Scientist
Research and development of X-ray dosimetry, applied and standard dosimetry, measurement and calibration techniques, standard dosimetry, quality assurance, calibration services

Teuvo Parviainen, MSc (Health Science), Scientist
Research and development of X-ray dosimetry and quality assurance, applied and standard dosimetry, education and training in radiation protection, expert and calibration services, quality assurance

Radiotherapy and Nuclear Medicine

Ritva Bly, LicPhil (Physics), medical physicist, Head of Section
Regulatory activities, management, quality management, research and development in the medical use of radiation, radiotherapy dosimetry, radiation safety, patient dose evaluation

Helinä Korpela, LicPhil (Chemistry), Senior Inspector
Regulatory activities in nuclear medicine, quality assurance, inspections of nuclear medicine units at hospitals, research and development in radiation safety, patient dose evaluation

Petri Sipilä, MSc (Physics), Senior Inspector
Regulatory activities in radiotherapy, inspections of radiotherapy units at hospitals, research and development in radiotherapy dosimetry and radiation safety, standardisation

Jarkko Niemelä, MSc (Physics), Inspector
Regulatory activities in radiotherapy and nuclear medicine, inspections of radiotherapy units and nuclear medicine departments at hospitals, research and development in radiotherapy dosimetry and radiation safety

Katja Merimaa, MSc (Physics), Physicist
Regulatory activities in radiotherapy and X-ray diagnostics, inspections of radiotherapy and X-ray diagnostic units at hospitals, research and development in CT dosimetry and radiation safety

X-rays in Health Care

Petra Tenkanen-Rautakoski, MSc (Tech), Head of Section
Regulatory activities, management, quality management, research and development in the medical use of radiation

Juhani Karppinen, MSc (Physics), Senior Inspector
Regulatory activities in diagnostics, inspections of radiological units in hospitals, patient dose measurements, research and development in X-ray dosimetry and radiation safety in diagnostics

Markku Pirinen, MSc (Physics), Senior Inspector
Regulatory activities in X-ray diagnostics, quality assurance, inspections of diagnostic units at hospitals, research and development in X-ray dosimetry and radiation safety in diagnostics

Radiation in Industry

Eija Venelampi, MSc (Tech), Senior Inspector
Regulatory activities in uses of radiation in industry and NORM industries, research and development in radiation safety

Santtu Hellstén, MSc (Tech), Inspector
Regulatory activities in uses of radiation in industry, inspections of various types of facilities, research and development in radiation safety.

Markku Koskelainen, BSc, MSc (Physics), Inspector
Regulatory activities in uses of radiation in industry, inspections of various types of facilities, research and development in radiation safety and stakeholder involvement in decision making.

Jyri Lehto, MSc (Chemistry), Inspector
Regulatory activities in uses of radiation in industry, inspections of various types of facilities, research and development in radiation safety.

4.10 Non-Ionizing Radiation Surveillance

The unit of Non-Ionizing Radiation Surveillance was established in 1977.

4.10.1 Key words and specific technologies

Non-Ionising Radiation (NIR), static magnetic field, low-frequency electric (E) and magnetic (H) fields, radio-frequency electromagnetic (EM) fields, extra low frequency (ELF) fields, microwaves, infrared radiation, visible light, ultraviolet (UV) radiation, laser radiation. Power lines, indoor transformers, magnetic resonance imaging (MRI) devices, electronic article surveillance devices (EAS), metal detectors, radio-frequency identification devices (RFID), high-frequency heaters, broadcasting stations, mobile phones, base stations, microwave dryers, radars, lasers and laser pointers, sunlamps and sunbeds, UV phototherapy, solar UV radiation.

EM field measurement techniques, exposure measurements, Specific Absorption Rate (SAR) measurements, metrology, calibration, primary and secondary standards, traceability, Helmholtz coil, TEM transmission cell, waveguide chamber, anechoic chamber, calibrated antenna, automated SAR measurement system, calorimetry, *in vitro* exposure chamber, *in vivo* exposure chamber, quartz-halogen lamp, detector-based calibration, filter radiometer, portable calibrator, radiometry, UV radiation dosimetry, broadband UV radiometers, spectroradiometers, solar UV radiation measurements, weighted magnetic field measurement, numerical EM field dosimetry, experimental RF dosimetry.

4.10.2 Description of laboratory activities

STUK is a national authority for the regulation and surveillance of general public exposure to NIR and a national expert body in all safety issues of NIR. The basic tasks as an authority are as follows:

- to ensure that the regulations and standards limiting exposure of the general public to NIR are up to date
- to carry out NIR surveillance tasks stipulated by the radiation protection legislation (general public)
- to provide reliable and clear information on NIR to the general public, media, authorities and users of NIR appliances

The regulatory and standardisation tasks are

1. preparation of proposals for new national radiation safety regulations and guidelines, which include exposure limits, STUK guides for applying the exposure limits and technical standards for exposure assessment
2. participation in the preparation of international radiation safety standards

The NIR surveillance tasks are
1. market surveillance of products and devices emitting electromagnetic fields and optical radiation (for example mobile phones and laser pointers)
2. environmental surveillance of electromagnetic fields in the general living environment (mobile phone base stations, high voltage power lines)
3. field surveillance (solaria, laser shows)
4. special surveillance tasks (radio and radar stations, radiation safety stipulations of the Finnish Defence Forces)

Typical expert services include
1. calibration of UV radiation monitors and meters
2. calibration of EM field strength meters
3. assessment of EM field risks in the occupational environment (high frequency heaters, broadcasting stations, radar stations, arc furnaces, induction heaters, etc.)
4. assessment of UV risks in the occupational environment

The regulatory functions and expert services are not considered in more detail in this report, where the main focus is on the research and related activities.

Research

The research on NIR is aimed at developing new exposure limits, improving expertise in exposure assessment (measurement techniques and computational methods) and determining exposure in critical exposure situations. In addition to NIR exposure assessment, the biological effects of UV radiation have been examined in various studies.

- Exposure to static and ELF gradient magnetic fields was investigated in an internal project (Radiation safety of magnetic resonance imaging, 2007–2008, MUST) on occupational safety when working with MRI devices.
- A proposal was prepared to limit the electrical field induced in the body of a person moving in a strong static magnetic field.
- A new exposure assessment method was developed for operators of RF dielectric heaters.
- Workers' exposure to ELF magnetic fields at indoor distribution substations was assessed with computations in a national project (Magnetic field safety at indoor distribution substations, 2008–2009, MF Safety) partly financed by Tekes – the Finnish Funding Agency for Technology and Innovation.

- Exposure to EM fields radiated by base station antennas was examined with SAR and field strength measurements in a national project (Software development for computational EMF dosimetry, 2006–2007, EMSOFT) partly financed by Tekes.
- Exposure systems and RF dosimetry were developed for biological studies in two national projects (Health Risk Assessment of Mobile Communications, 2004–2007, HERMO and Wireless Communication Devices and Human Health, 2009–2011, WIRECOM) that were partly funded by Tekes and industry.
- Calibration methods were developed for SAR probes below 400 MHz and for limb current measuring devices in the frequency range from 10 to 110 MHz in an international metrological project (Traceable measurement of field strength and SAR for the Physical Agents Directive, 2008–2011, EMF and SAR), which formed part of a European Metrological Research Program and was partly funded by the EC.
- The effect of UVA radiation on melanoma metastasis was investigated using *in vivo* mouse model.

Theses

During 2005–2010 the following theses were completed:

- Sami Kännälä, MSc thesis, 2005 (Kännälä 2005)
- Ari-Pekka Sihvonen, MSc Pro Gradu thesis, 2006 (Sihvonen 2006)
- Riikka Pastila, DrSc thesis, 2006 (Pastila 2006)
- Tommi Toivonen, DrSc thesis, 2010 (Toivonen 2010)

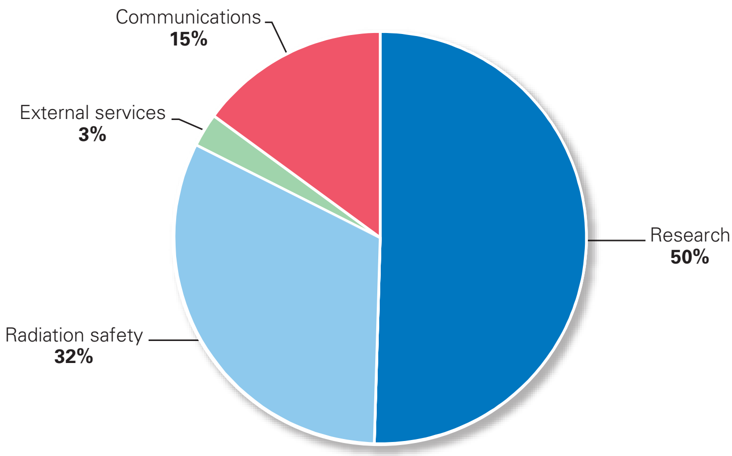
Dissemination of expertise and information

An undergraduate course has been held every second year at the School of Electrical Engineering of Aalto University on the biological effects and measurement of electromagnetic fields and optical radiation. Numerous lectures have been given in various training courses and seminars.

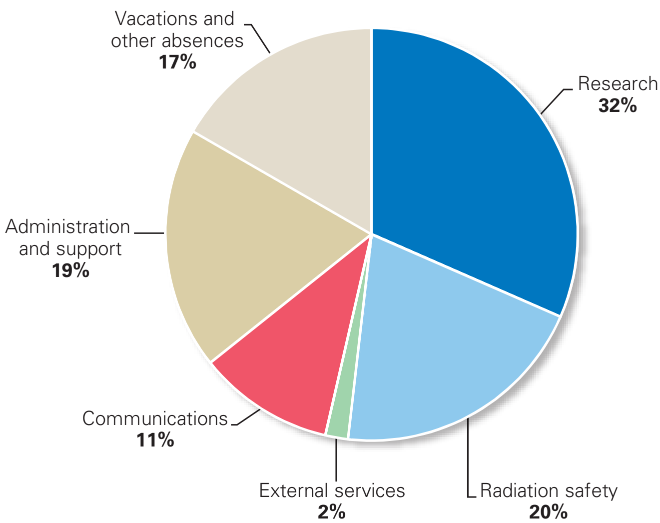
The experience gained from the research and regulatory activities since 1977 has been condensed into two textbooks. A book on electromagnetic fields was published in 2006 and another on laser and UV radiation in 2009. These books are included in the book series of STUK, which consists of seven books dealing with radiation and nuclear safety. Non-Ionising Radiation Surveillance wrote two of the seven books, which was a substantial task for the personnel, comprising a relatively small number of people.

Key information on the resources used for different activities (total costs and effective working time) is provided in the following figures.

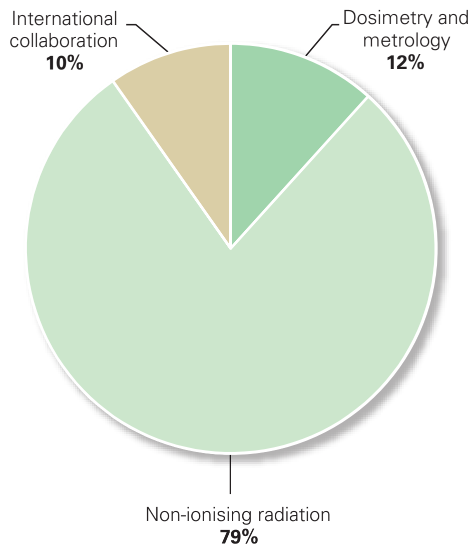
Total costs 998 k€ distributed by sectors in 2010



Effective working time by sectors in 2010
Total person-years 9.3



Effective working time of research by areas in 2010
Total person-years 2.9



4.10.3 Personnel

At the end of 2010, there were altogether nine permanent positions in the unit of Non-Ionizing Radiation Surveillance:

Kari Jokela, DTech, Head of Laboratory (until June 2011), Research Professor
Management, EM fields, optical radiation, development of regulations and guidelines for radiation safety, international expert tasks for the development of new guidelines on the limitation of human exposure to NIR

Riikka Pastila, PhD (Biochemistry), on the leave as a post-doc scientist 2008–June 2011, Head of Laboratory (June 2011–)
Risk evaluation for UV radiation, studies on the biological effects of UV radiation

Lauri Puranen, LicTech, Senior Inspector
Management, standardisation, risk evaluation and communication for human exposure to EM fields, project manager

Reijo Visuri, MSc, Senior Inspector
Surveillance and development of surveillance for solaria and lasers, standardisation

Tommi Toivonen, DTech, Senior Scientist
Standardisation, risk evaluation and communication for human exposure to EM fields

Lasse Ylianttila, MSc (Tech), Senior Scientist
Surveillance of lasers and solaria, optical radiometry, UV exposure assessment

Sami Kännälä, MSc (Tech), Scientist
Numerical dosimetry and risk evaluation for EM fields

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5 Summary of the previous external evaluations and development of government research system

5.1 International evaluation of STUK research activities in 2005

At the request of the Finnish Ministry of Social Affairs and Health, an international team of four experts evaluated STUK's research activities in 2005. The evaluation team familiarised with STUK's research activities by visiting STUK, interviewing the scientists and examining the ample written material delivered to the team in advance. This evaluation was the second international evaluation and the panel noted with satisfaction that STUK had carefully analysed and taken into account the recommendations of the international review team in 2000. Many of the recommendations had successfully been implemented in organising the work tasks and the professional profile of STUK had also become more visible since 2000 both in Nordic countries and in the international scene. The panel found that STUK has reinforced its position as a top research institute in its field, largely due to the multidisciplinary know how and its integration in the main European or international projects. STUK's research was considered in many areas to be high or even the highest quality.

However, in its report in early 2006[1)], the evaluation team also made several recommendations on management and scientific issues in order to reinforce the quality of research activities at the Institute.

The recommendations concerning the research activities at STUK were carefully analysed by the research units and management in 2006. There were altogether 53 recommendations, 10 of which were of general nature and the rest addressed to individual laboratories. Many of the recommendations could be pooled and therefore the number of development actions taken in consequence of the evaluation of research activities is approximately 40. In the follow-up of the actions, it was concluded that more than 90% of them had taken place already by 2007. A summary of the main development actions is given below.

STUK has decided to perform an evaluation of its research activities every fifth year. The aim is to keep STUK among one of the leading research institutes in Europe or even in the whole world and to maintain the research publications comparable with other corresponding institutes.

1 International Evaluation of the Research Activities of the Finnish Radiation and Nuclear Safety Authority (STUK). Ministry of Social Affairs and Health, Reports 2006:60.

An organisational change of the laboratories in the Department of Research and Environmental Surveillance was made in 2007 and two laboratories were further fused in 2009 in order to ensure the critical mass of resources in the laboratories. A major change was pooling the laboratory analyses into one new laboratory, Radionuclide Analytics. At the same time, the previous laboratories of Radioecology and Foodchains and the Nuclear Power Plant Environment were fused into Environmental Research Laboratory. Furthermore, a new Laboratory of Security Technology focusing on research and technological development was established from the previous Laboratory of Airborne Radioactivity. The new laboratory of Environmental Surveillance and Preparedness now focuses on nation wide monitoring and clarifies the responsibilities on emergency preparedness.

More attention has been paid to passing the expertise on when STUK experts with crucial knowledge are retiring. This has been carried out by better documentation of research projects and improved databases, the new book series, internal training, mentoring and, in some cases, by employing new staff prior to the retirement of key experts.

Publishing all the relevant data STUK has generated is an important objective while publication in peer reviewed journals has also been emphasised. Over the years, there has been a steady increase in the number of original publications but a recent drop raises some concern.

In order to improve collaboration between the STUK laboratories, a new value of co-operation for whole STUK was introduced. New co-operation groups have been established for nuclear security, uranium, radioactive waste, radiation metrology and research ethics.

The cooperation with universities was enhanced by participating in graduate schools, giving guidance to university and thesis students and investing in further training of STUK staff.

The publication performance was improved by arranging courses in scientific writing and statistical analyses and by devoting time of experts close to the retirement age for the writing of articles.

Since the last evaluation, the process for adopting and prioritising new projects has been developed. The load of work has been reduced as well as the number of projects. However, as the resources have declined in parallel, there are still tasks and projects in abundance compared with the number of employees.

5.2 Structural development of government research system

In 2004, the government of Finland launched an evaluation of the needs for structural development of governmental research systems, including universities, sectoral research centres and funding organisations. For this purpose, the topics for research and the organisation and funding of research carried out by STUK was also evaluated, as STUK is one of the sectoral research institutes in Finland.

The main conclusions were that STUK has no overlapping research activities with other governmental research institutes, STUK is a well organised research centre and its research is cost- efficient. As compared to other governmental research institutes, the level of external funding is low, only about 15% of total funding.

Since the previous international evaluation mission to STUK in 2005, the governmental R&D evaluation and development mission has continued. Prospects for reorganisation of the government research system and duties of institutes have been explored widely. The Advisory Board for Sectoral Research was established in 2007 and abolished in 2010. During its operation, the Advisory Board defined five major clusters for policy-driven research: natural resources and environment, health, wellbeing and culture, safety and security, competence, work and innovations, and constructed environment, living and infrastructures. STUK activities belong into all these categories.

Significant changes in higher education and science policy in Finland took place in 2009–2010. The act implementing the new Universities Act entered into force in August 2009, enabling the reorganisation of the universities. From the beginning of 2010, universities acquired the status of independent legal persons and were separated from the State. However, the State will continue to be the primary financier of the universities; universities are after all the foundation of the Finnish innovation system and the most central institution in terms of innovating education and culture. The Polytechnics Act and laws governing the Academy of Finland were also amended to correspond to the forms of activities and modern administrative models stipulated under the new Universities Act.

In 2011, collaboration between the research institutes under Ministry of Social Affairs and Health has been strengthened by creation of a new legal entity, SOTERKO, Consortium of the Expert Authorities for Social Welfare and Health Care. SOTERKO has joint research programmes in which institutes participate with their own budget and personnel. STUK is coordinating the programme “Improved health and well being via the management of risks”.

6 Review of main results 2005–2010

6.1 Publications and other dissemination outcomes

6.1.1 Publications

The number of research publications in 2000–2010 is presented in Figure 16. The publication categories include original publications (articles in international peer-reviewed journals), articles in the proceedings of international scientific meetings, and reports published in the institutes' own publication series. Publishing in peer-reviewed international journals and for a wider audience is encouraged. Publications are used as a measure of research productivity. STUK has an internal impact score for different types of publications: 12 points for an original publication, 8 for a proceedings article, 4 for a report and 2 for an international meeting abstract or an article in a national professional journal. The objective is that STUK will publish one peer-reviewed article per academic researcher-year. This objective has been exceeded. Another objective within STUK is to score at least 900 publication points. This objective has also been achieved during recent years.

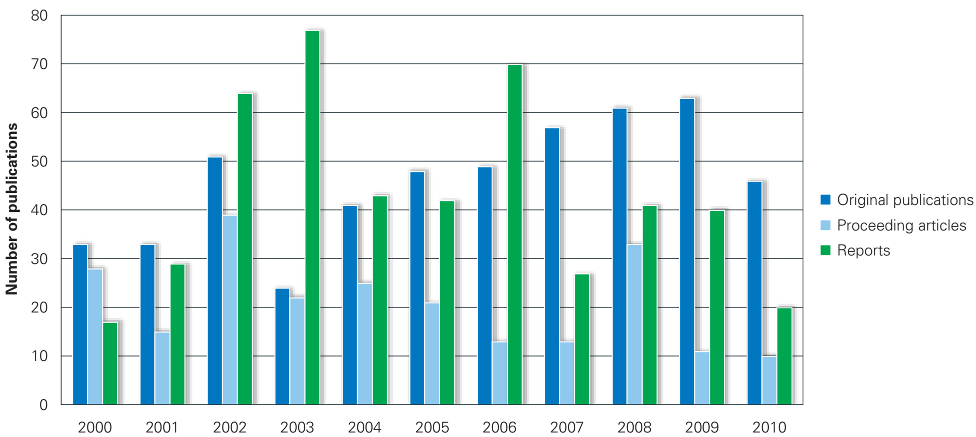

Figure 16. Number of research publications in the three publication categories during 2000–2010.

A list of peer-reviewed publications, proceedings articles and other major research reports for the last six years is given at the end of this report. The number of research publications has followed an increasing trend over the years. During 1995–1999, an average of 28 original articles was published per

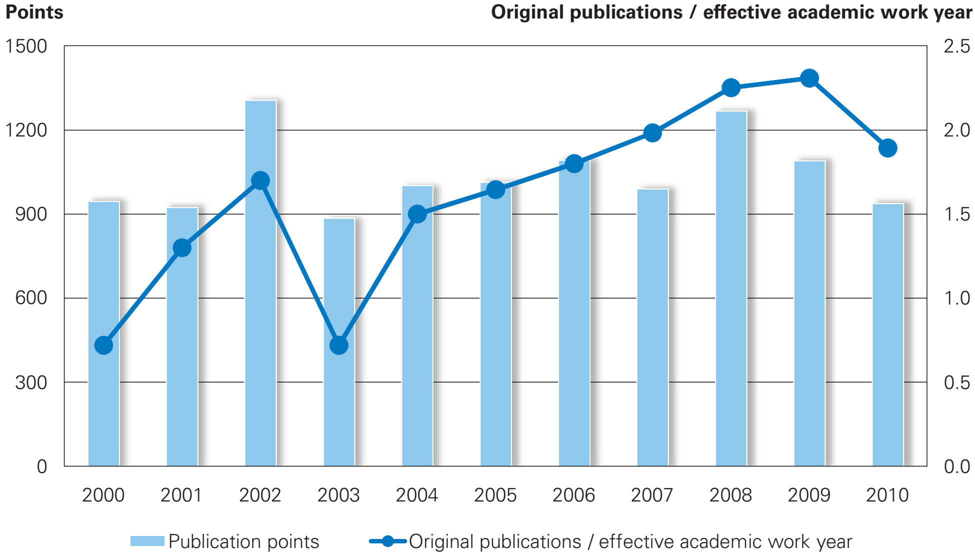

Figure 17. Publication points and the number of original publications per effective academic work year in 2000–2010. The goal set by the Ministry of Social Affairs and Health has been 900 publication points and 1 original publication per effective academic work year.

year, whereas during 2000–2005 the respective figure was 38 per year, and in 2006–2010 the average was 55. This increase is partly explained by internal training on scientific writing, higher academic training level of personnel and increased participation in international research projects.

About 60 experts at STUK have contributed to the new Radiation and Nuclear Safety book series (in Finnish). Five books were published during the previous reporting period: Radiation and its detection (2002), Health effects of radiation (2002), Radiation in the environment (2003), Use of radiation (2004), and Nuclear safety (2004). More recently, two more books on non-ionising radiation have been published: Electric and magnetic fields (2005) and Ultraviolet and laser radiation (2009).

6.1.2 Actions to popularise research results

Many of STUK's research results are of interest to the public, decision makers and stakeholders. STUK's information policy is open and proactive. In the case of research results, the routine procedure is to pass a popularised summary of the results to the Information Unit immediately after their publication in an article or report. The information officers make use of the summaries for the STUK web site, press releases and other information materials. The public are very interested in news dealing with radiation or nuclear safety, and the media takes up practically all STUK press releases. Training of scientists includes instruction on communicating with the media, which is also practised in emergency exercises.

Scientific expertise on the effects of radiation and its occurrence in the environment has increased the general credence of STUK. The past 25 years have demonstrated that the mass media and private citizens most often contact experts of STUK whenever news or rumours on radiation appear. On the other hand, STUK itself has also focused resources on public communication in order to provide the necessary information expeditiously and in a professional way. In 2010, STUK used 3% of its resources for public communication. STUK's communication is proactive, open, timely and understandable. Experts can be reached at any time, including nights, weekends and holidays via an information officer duty system.

There are several means of popularising results and of communicating with the public and stakeholders:

- Articles published in national professional journals, such as STUK's own journal, ALARA. These articles are primarily targeted at stakeholders.
- Information brochures
- Books on radiation and nuclear safety (the STUK book series)
- Internet pages (*www.stuk.fi*), which were partially updated during 2009, including questions for experts and answers within two days
- Nearly 15 000 visitors per month to the Finnish pages, 4 000 to the English pages
- The most popular were the radon pages, followed by pages providing latest information on dose rates around Finland
- 500–660 questions for experts per year were received, as mentioned above
- Press releases and press conferences, interviews
- Training courses, seminars and lectures aimed at stakeholders, for example “Secrets of Radiation” training courses for journalists
- Receiving visitor groups of for example different student organisations
- Fair and exhibition stands
- Information via telephone

6.2 Health effects of radiation

6.2.1 Biological effects of low doses of ionising radiation

Individual susceptibility

Individual susceptibility factors in the yield of chromosomal aberrations were investigated from blood samples obtained from Estonian Chernobyl cleanup workers. The yield of stable chromosomal aberrations, i.e., translocations, has been evaluated in Estonian males who participated in the cleaning operations after the Chernobyl accident in 1986. The work involved translocation analysis applying FISH chromosome painting of 316 exposed and 87 controls, whose lymphocyte samples were obtained between 1993 and 1997. Translocation frequencies, which can be used in dose reconstruction of past exposures, show individual variation. Age is the major contributor to the variation, but other factors may also influence the frequency of translocations, such as DNA polymorphisms occurring in DNA repair and cell cycle control genes. Altogether, 17 single nucleotide polymorphisms (SNPs) were determined in DNA repair and cell cycle control genes: *ATM* (ataxia telangiectasia mutated) (codons 858, 1054, and 1853 and two intronic SNPs), *CASP8* (caspase 8) (codons 5 and 302), *LIG4* (ligase IV) (codons 9 and 568), *XRCC1* (X-ray repair cross-complementing group 1) (codons 194, 280, and 399), *XRCC3* (X-ray repair cross-complementing group 3) (codon 241), *XRCC5* (X-ray repair cross-complementing group 5) (codon 5 and an intronic SNP) , and *XRCC6* (X-ray repair cross-complementing group 6) (codon 593 and an intronic SNP). In addition, the genotypes of two xenobiotic metabolism genes (*GSTM1*, glutathione S-transferase, MU-1 and *GSTT1*, glutathione S-transferase, theta-1) were defined. Possible associations of polymorphisms, the registered dose and other confounders with the yield of translocations will be assessed in statistical testing employing multivariate regression analysis.

In continued studies of the CancerRiskBiomarkers project, a large European cohort study repeatedly demonstrated that a high frequency of structural chromosome aberrations (CAs) in peripheral lymphocytes is predictive of an increased cancer risk (Norppa et al. 2006). The evidence indicates that both chromatid-type and chromosome-type CAs predict cancer, even though some data suggest that chromosome-type CAs may have a more pronounced predictive value than chromatid-type CAs. SCE frequency does not appear to have cancer predictive value, at least partly due to uncontrollable technical variation. A number of genetic polymorphisms of xenobiotic metabolism, DNA repair, and folate metabolism affect the level of CAs and might collectively contribute to the cancer predictivity of CAs. We investigated the potential role of DNA repair polymorphisms in the chromosomal aberration frequency at the individual level in a cohort of 84 persons (Kiuru et al. 2005). Genotypes of DNA repair genes *OGG1* (8-oxo-guanine DNA glycosylase 1) (codon 326), *XPD* (Xeroderma pigmentosum group D) (codon 751), *XRCC1* (X-ray repair cross-complementing group 1) (codons 194, 280, and 399), and *XRCC3* (X-ray repair cross-complementing group 3) (codon 241) were determined. Our data suggest that the *XRCC1* 280His and *XRCC3* 241Met alleles affect individual CA levels, most probably by influencing the DNA repair phenotype.

Non-targeted effects

The NOTE (Non-targeted effects of ionising radiation) project (2006–2010) aimed to expand current understanding of the health effects caused by low-level doses of ionising radiation.

The Laboratory of Radiation Biology contributed to the three experimental studies in the NOTE project.

Non-targeted effects in 3D culture systems

Non-targeted effects after microbeam irradiation were studied in the EpiAirway (MatTek, USA) artificial 3D human tracheal/bronchial tissue systems. The bystander effect was seen in some experiments, but further studies are needed to confirm the results. Most of the data were generated using apoptosis as the endpoint. However, the overall background frequency of apoptosis was very low and the level of apoptosis can vary between doses in an experiment and between experiments.

Characterisation of clastogenic factors from the plasma of irradiated subjects – a pilot study (CLASTO)

In studies reported as early as in the 1960s, and in several subsequent investigations, plasma from irradiated individuals has been shown to induce chromosomal aberrations when transferred into normal blood cultures. We have investigated the occurrence of these clastogenic factors (CF) using markers representing DNA damage (chromosomal aberrations, micronuclei and γH2AX) produced in reporter lymphocytes that were treated with plasma from locally exposed individuals. Blood plasma was obtained from clinical patients with benign conditions before and after they had been exposed to high- and low-dose radiation to very small or small treatment volumes. Local radiation exposure seemingly had no effect on the induction of CF in patient plasma, and no deviation in chromosomal aberration, micronuclei or foci induction was observed in reporter cells treated with post-exposure plasma with respect to pre-exposure samples. Newly taken plasma samples from three radiological accident victims exposed in 1994 were investigated. In contrast to the patient data, a significant increase in chromosome aberrations was induced with plasma from two of the accident victims.

Identification of the clastogenic factors (CF) was attempted applying biochemical techniques, particularly 2DE-based proteomics. The analyses revealed that the local exposure did not have detectable effect on protein levels in any patient group. Furthermore, the 2DE protein data revealed that for radiation accident victims small MW proteins displayed modification in their expression level in comparison to controls, and these may be considered as potential clastogenic factors. The identification of these possibly radiation-induced proteins is underway, and this may provide information on the mechanisms of action in the CF phenomenon.

Individual sensitivity in non-targeted effects of radiation – ATM as a model for characterising individual susceptibility (ATModel)

The main aim of this study was to investigate the role of genetic heterogeneity with respect to individual variation in the non-targeted response to ionising radiation. The ATM (Ataxia telangiectasia mutated) gene was used as a model for characterising the role of repair genes in the non-targeted effect. ATM is known to be a major activator of cellular responses to DNA double-strand breaks and is involved in several signalling pathways, including cell cycle control and mitotic recombination. The experimental system was based on a co-culture system where irradiated cells can communicate with unirradiated cells immediately post-irradiation. Cells were irradiated with 0, 0.01, 0.1, 1, or 2 Gy of X-rays (100 kV, wide range energy spectrum). In general, it can be concluded that no bystander effect was observed applying the described experimental setting with a co-culture system, 100 kV X-rays and using cell viability and chromosomal aberrations as endpoints. The same outcome was observed for all ATM cell lines representing different AT mutation genotypes. In contrast, directly irradiated cell lines did show decreased viability in a dose-dependent manner and a clear dose response was detected in the chromosome-type aberrations in all irradiated cell lines (the ATModelDirect project (2009–2010) (unpublished data).

Non-cancer diseases

Epidemiological studies have indicated that low doses of ionising radiation, as low as 100–500 mGy, may induce cardiac damage, but the mechanism of such effect is unknown. The vascular endothelium has been suggested as a potential target tissue. Using the EA.hy926 human endothelial cell line, teams at HMUC in Munich, Germany, and at STUK in Helsinki, Finland have evaluated the time-dependent changes in the cytoplasmic proteome induced by low-dose ionising radiation (Co-60 gamma ray total dose 200 mGy; 20 mGy/min and 190 mGy/min) (the CARDIORISK project). Using the proteomics approach (2D-DIGE technology, MALDI-TOF/TOF tandem mass spectrometry, and peptide mass fingerprint analysis), 15 differentially expressed proteins were identified (more than ±1.5-fold difference compared to unexposed cells) (Pluder F et al. 2010). Pathways influenced by the low-dose exposures included the Ran and RhoA pathways, fatty acid metabolism and stress response. In conclusion the study has indicated that low-dose ionising radiation affects the cytoplasmic proteome of a human endothelial cell line in a subtle but significant manner, the biggest impact being observed immediately (4 h) after irradiation. The higher dose rate used here (190 mGy/min) induced far more proteome alterations than the low dose rate (20 mGy/min). A common feature of many of the cytoplasmic proteins identified as low-dose radiation-responsive is that the signalling pathways they represent are directly dependent on the redox potential and the level of reactive oxygen species. Further experiments are ongoing at STUK and HMUC and will be submitted for publication in 2011.

6.2.2 Biological effects of non-ionising radiation

Effects on human endothelial cells *in vitro*

Studies on the effects of mobile phone radiation on human endothelial cell lines were funded by research grants from the Academy of Finland, the Technology and Development Center of Finland (Tekes; La Vita project) and the EU 5th Framework Research Program (Reflex project). These studies were a direct continuation of earlier research published in 2002–2004.

Studies using 900 MHz GSM radiation

Using two variants of the human endothelial cell line (EA.hy926 and EA.hy926v1), we have demonstrated alteration in the gene and protein expression of both examined cell lines in response to one hour of mobile phone radiation exposure at an average specific absorption rate of 2.8 W/kg (Nylund and Leszczynski 2006). However, the same genes and proteins were differently affected by the exposure in each of the cell lines. This suggests that the cell response to mobile phone radiation might be genome- and proteome-dependent. Therefore, it is likely that different types of cells and from different species might respond differently to mobile phone radiation or might have different sensitivity to this weak stimulus. This finding might explain, at least in part, the origin of discrepancies in replication studies between different laboratories.

A similar result of a possible cell type-dependent effect of mobile phone radiation on the gene expression level has been obtained in study in which several research groups of the Reflex project have contributed, including STUK (Remondini et al. 2006). Using several different types of cell lines it was shown that partially different sets of genes respond to mobile phone radiation in different cell types.

Studies using 1800 MHz GSM radiation

EA.hy926 were exposed to 1 800 MHz GSM radiation to determine whether the same response is induced in them as the response observed in earlier studies using 900 MHz GSM radiation (Nylund et al. 2009). The obtained results suggest that the 900GSM and 1 800GSM exposures might affect the expression of some, but possibly different, proteins in the EA.hy926 cell line.

Using primary human umbilical vein endothelial cells and primary human brain microvascular endothelial cells as models, we have examined whether exposure to 1 800 MHz GSM mobile phone radiation can differently affect the cell proteome, as shown earlier for 900 MHz GSM radiation. Our results suggest that 1 800 MHz GSM radiation did not affect protein expression when the proteomes were examined immediately after the end of the exposure and when correction for the false discovery rate was applied in the analysis (Nylund et al. 2010). This observation agrees with our earlier study showing that exposure to 1 800 MHz GSM radiation had only a very limited effect on the proteome of the human endothelial cell line EA.hy926, as compared to the effect of 900 MHz GSM radiation.

Effects on human skin *in vivo*

Earlier *in vitro* studies have revealed that mobile phone radiation (radiofrequency modulated electromagnetic fields; RF-EMF) alters protein expression in human endothelial cell lines. This does not automatically mean that a similar response will take place in the human body exposed to this radiation. Therefore, a pilot human volunteer study has been executed using the proteomics approach to examine whether local exposure of human skin to RF-EMF will cause changes in protein expression in living people (Karinen et al. 2008). A small area of skin on the forearm of 10 female volunteers was exposed to RF-EMF (specific absorption rate SAR = 1.3 W/kg) and punch biopsies were collected from exposed and non-exposed areas of skin. Proteins extracted from biopsies were separated using 2-DE and protein expression changes were analysed using PDQuest software. Analysis has identified 8 proteins that were statistically significantly affected (Anova and Wilcoxon tests). Changes in two of the proteins were present in all 10 volunteers. This suggests that protein expression in human skin might be affected by exposure to RF-EMF. The number of affected proteins was similar to that observed in our earlier *in vitro* studies. In conclusion, this was the first study showing that molecular level changes might take place in human volunteers in response to exposure to RF-EMF. Our study confirms that the proteomics screening approach can identify protein targets of RF-EMF in human volunteers.

Effects on human sperm *ex vivo*

A research project examining the effects of mobile phone radiation on human sperm has been executed in collaboration with the University of Pretoria Nadia Falzone and Dr Carin Huyser), the South African Bureau of Standards (SABS; Dr. Francis de la Roux Fourie) and Stellenbosch University (Prof. Daniel Franken). STUK's irradiation chamber for 900 MHz GSM mobile phone radiation was on loan to the SABS for the period of execution of the project. Recent studies have indicated that radiofrequency electromagnetic fields (RF-EMF) might have an adverse effect on human sperm quality, which could translate into an effect on fertilisation potential. Effects of mobile phone radiation (900 MHz GSM; SAR 2.0 and 5.7 W/kg) on human sperm were examined using ejaculated, density purified human spermatozoa (Falzone et al. 2008, 2010, 2011).

The following properties of human spermatozoa were examined:

- sperm mitochondrial membrane potential – no effect
- two sperm kinematic parameters: straight line velocity (VSL) and beat-cross frequency (BCF) were significantly impaired ($p < 0.05$) after the exposure at SAR 5.7 W/kg
- sperm acrosome reaction – no effect
- analysis of sperm morphometric parameters has shown a significant reduction in sperm head area (9.2 ± 0.7 lm2 vs. 18.8 ± 1.4 lm2) and acrosome percentage of the head area (21.5 ± 4% vs. 35.5 ± 11.4%)
- sperm−zona binding was significantly reduced directly after exposure
- no statistically significant effect on any of the pro-apoptotic parameters of sperm (caspase-3 activity, externalisation of phosphatidylserine (PS), induction of DNA strand-breaks, and generation of reactive oxygen species) was detected.

Altogether, these results suggest that mobile phone radiation might affect the fertilisation potential of sperm. However, mobile phone radiation seems not to induce DNA damage or cell killing, or affect the sperm mitochondrial membrane potential or sperm acrosome reaction.

Effects on *C. elegans in vivo*

This project has been executed in part at STUK and has been a collaboration between the University of Nottingham, UK, the Swiss Institute of Technology and STUK. Recent data suggest that there might be a subtle thermal explanation for the apparent induction by radiofrequency (RF) radiation of transgene expression from a small heat-shock protein (hsp16-1) promoter in the nematode *Caenorhabditis elegans* (Dawe et al. 2008). The RF fields used in the *C. elegans* study were much weaker (SAR 5–40 mW/kg) than those routinely tested in many other published studies (SAR 2W/kg). To resolve this disparity, we have exposed the same transgenic hsp16-1::lacZ strain of *C. elegans* (PC72) to higher intensity RF fields (1.8 GHz; SAR 1.8W/kg). For both continuous wave (CW) and Talk-pulsed RF exposures (2.5 h at 25 °C), there was no indication that RF exposure could induce reporter expression above sham control levels. Thus, at a much higher induced RF field strength (close to the maximum permitted exposure from a mobile telephone handset), this particular nematode heat-shock gene is not up-regulated. However, under conditions where background reporter expression was moderately elevated in the sham controls (perhaps as a result of some unknown co-stressor), we found some evidence that reporter expression may be reduced by ca. 15% following exposure to either Talk-pulsed or CW RF fields.

UV radiation and skin

Ultraviolet (UV) radiation is considered the major factor in skin cancer development, but the possibility that it may affect melanoma metastasis has not been widely addressed. We have investigated the effect of solarium-derived UV-A (320–400 nm) irradiation on the metastatic capacity of mouse melanoma, reporting a possible link between UV radiation exposure and melanoma metastasis both *in vitro* and *in vivo.* UVA irradiation was found to enhance the metastatic properties of mouse melanoma B16 cell lines by increasing the adhesiveness of melanoma cells to endothelium, and by changing the expression pattern of adhesion molecules when melanoma cells were exposed *in vitro* to UVA radiation (Pastila and Leszczynski 2005a). In addition, the used UVA dose was found to induce expression changes in the nine differentially expressed genes that are involved in the cell cycle, angiogenesis, stress-response and cell motility (Pastila and Leszczynski 2007). This postulates that the observed genes might be involved in the cellular response to UVA and a physiologically relevant UVA dose has previously unknown cellular implications.

We have also shown that UV-A exposure of mice *in vivo* increased the formation of melanoma lung metastases in C57BL/6 mice injected *i.v.* with low-metastatic B16-F1 cells (Pastila and Leszczynski 2005b). The latest results have confirmed that 14 days after treatment, mice injected *i.v.* with B16-F1 cells and exposed to UVA developed 4 times more lung metastases than the non-exposed group (manuscript under revision). However, the *in vitro* exposure of melanoma cells prior to injection into mice led to the induction only of 1.5 times more metastases as compared to the animals injected with non-irradiated cells. Therefore, UVA-induced changes in the adhesive properties of melanoma cells cannot alone account for the metastasis increase observed after *in vivo* exposure of mice. One reason behind the increased metastatic potential of the melanoma cells could be a UV-induced decline in cellular immunity, which has been shown to help in the progression of melanoma by impairing the rejection of invasive tumour cells in the UV-exposed host. The UVA-induced immunosuppression was measured by a standard contact hypersensitivity (CHS) assay and UVA was shown to cause a mild 14–16% systemic immunosuppression in mice that received UVA irradiation. Thus, the observed pro-metastatic effect of UVA might be at least partially due to UVA affecting the immune response (Pastila et al. 2011).

In the applied experimental metastasis model, the fate of the melanoma cells in the mouse circulation and body after melanoma cell injection has remained obscure. Therefore, the ongoing study was designed to investigate the metastatic process in real time utilising different *in vivo* molecular imaging technologies. The aim is to determine how UV exposure of the mouse *in vivo* affects melanoma cell circulation kinetics, cell trafficking to the host organs, and their long-term ability to form metastases. The preliminary results suggest that there are no significant differences in the clearance rate of circulating melanoma cells between UVA-treated and control mice, determined by *in vivo* flow cytometry. Whole-body bioluminescence imaging, however, showed increased melanoma cell arrest in the lung 60 minutes after UVA exposure compared to controls. UVA irradiation also considerably enhanced the proliferation of B16-F1 cells as compared to the non-exposed group during the subsequent 14 days. Our results suggest that both enhanced adhesion to pulmonary vasculature and enhanced proliferation contribute to the observed UV-A effect on melanoma (manuscript in preparation).

The *in vivo* imaging technology was also utilised when studying UV-induced inflammatory erythema formation in mouse skin, a condition that is known to be involved in photocarcinogenesis. The UVB-derived (280–320 nm) inflammation in the mouse ear was followed using a 2-Photon imaging system, which is a non-invasive optical imaging modality allowing the real-time visualisation of cellular and subcellular components of the skin. We observed that a slightly inflammatory UV dose caused leukocyte influx into the skin of the mouse ear within hour after the end of irradiation (Li et al. 2010). Moreover, a dermal cell, possibly mast cell, was shown to attract leukocyte infiltrates out of circulation (manuscript submitted).

UV radiation also has positive effects, as it produces vitamin D in skin. Vitamin D production was studied during heliotherapy (Vähävihu et al. 2008) and by using narrowband UVB lamps (Vähävihu et al. 2010a). STUK provided the dosimetry for these studies. During the heliotherapy, different methods for UV-dose determination were compared (Vähävihu 2010b).

Studies examining the effects of long-wave ultraviolet radiation were part of the doctoral thesis of Riikka Pastila, executed at STUK under the supervision of D. Leszczynski. R. Pastila defended her thesis in 2006 (Pastila and Leszczynski 2005a, 2005b, 2007).

6.2.3 Environmental radiation and health

Indoor air radon and lung cancer

The risk of lung cancer associated with exposure at home to the radioactive disintegration products of naturally occurring radon gas was determined in a collaborative analysis of individual data from 13 case-control studies of residential radon and lung cancer carried out in 9 European countries (Darby et al. 2005, 2006). The studies included 7 148 cases of lung cancer and 14 208 controls. The mean measured radon concentration in the homes of people in the control group was 97 Bq/m^3, with 11% measuring >200 Bq/m^3 and 4% measuring >400 Bq/m^3. For cases of lung cancer the mean concentration was 104 Bq/m^3. The risk of lung cancer increased by 8.4% [95% confidence interval (CI) 3.0% to 15.8%] per 100 Bq/m^3 increase in measured radon (P = 0.0007). This corresponds to an increase of 16% (5% to 31%) per 100 Bq/m^3 increase in usual radon – that is, after correction for the dilution caused by random uncertainties in measuring radon concentrations. The dose-response relation seemed to be linear with no threshold and remained significant (P = 0.04) in analyses limited to individuals from homes with measured radon <200 Bq/m^3. The proportionate excess risk did not differ significantly with study, age, sex or smoking. In the absence of other causes of death, the absolute risks of lung cancer by the age of 75 years at usual radon concentrations of 0, 100, and 400 Bq/m^3 would be about 0.4%, 0.5%, and 0.7%, respectively, for lifelong non-smokers, and about 25 times greater (10%, 12%, and 16%) for cigarette smokers. Collectively, though not separately, these studies show appreciable hazards from residential radon, particularly for smokers and recent ex-smokers, and indicate that it is responsible for about 2% of all deaths from cancer in Europe.

Lung cancer deaths attributable to indoor air radon in Finland were calculated to be 275 cases annually (37 attributed to radon only, and 238 attributed to radon and smoking) (Mäkeläinen 2010). The number of smoking-related lung cancer deaths was 1 488 and for other causes than radon or smoking 228. The figures were based on Finnish Cancer Registry data from 2008.

Ultraviolet radiation exposure and skin cancers

Ultraviolet radiation (UVR) is the primary cause of skin cancers. However, retrospective exposure assessment of UVR is a challenge for epidemiological research aimed at evaluating the relation with health effects occurring years or decades after the exposure has taken place. Therefore, an objective and non-invasive quantitative method would be valuable for UVR exposure assessment. Photodamage reduces the amount of bound water in the skin, and thus, measuring the skin's dielectric constant may provide an opportunity for assessing the cumulative UVR exposure. In order to evaluate a proposed, non-invasive method for quantitative determination of past UVR by assessing photodamage, we measured the dielectric constant of the skin and compared it with questionnaire data and biological measures of UVR exposure (Kojo et al. 2008). Three measurements sessions were performed on 100 subjects over a period of 1.5 years. A questionnaire was used to obtain information on host factors and on the past UVR exposure. As a biological indicator of photoageing, the elastin content of the dermis was analysed from skin biopsies. The dielectric constant varied over time and was also related to the season. Only a weak relation was found between the dielectric constant and the UVR exposure indicators and host factors. The bioimpedance measurement does not seem to reflect the structural alterations in the skin caused by past UVR exposure, and thus it is not a useful instrument for the assessment of photodamage.

A time-series analysis of the trends of some indicators of population exposure to UVR and the incidence of cutaneous malignant melanoma (CMM) was conducted (Kojo et al. 2006). Clothing coverage of the body was evaluated from archival photographs and the proportion of uncovered skin was used as a measure of UVR exposure. Information on the number of sunny resort holidays, duration of annual holidays, and sunscreen sales were obtained. Data on CMM incidence were obtained from the Finnish Cancer Registry. Exposed skin area doubled from 1920 to 1985. The average duration of annual holidays increased 30-fold. The number of sunny resort holidays and the sales of sunscreens increased rapidly from 1980. UVR exposure was not immediately (0–4 years) related to the preceding CMM occurrence, whereas the period from 5–19 years prior to CMM occurrence might be the most relevant period. However, the findings of ecological studies may not be applicable at the individual level.

Two analyses of an early detection programme for skin cancer have been carried out. In a retrospective study, the sensitivity, specificity and predictive values of early detection of skin cancer were assessed (Oivanen et al. 2008). The study population consisted of 10 187 subjects attending the Pirkanmaa Cancer Society skin clinic between 1991 and 2000. Skin cancers were identified from the Finnish Cancer Registry. The detection rate for all skin cancers was 11.0 /1 000 subjects for campaigns and 22.6 / 1 000 subjects for routine activity ($p < 0.001$) and for CMM 0.8 / 1 000 and 2.8 / 1 000 subjects, respectively ($p < 0.05$). The number of attenders needed to detect one skin cancer case was 91 in campaigns and 44 in routine activity, and the corresponding figures for CMM were 1 181 and 428, respectively. The cumulative incidence of skin cancer within 24 months was 3.2% for routine and 1.6% for campaign attenders ($p < 0.001$). Sensitivity (82% for routine and 61% for campaigns, $p < 0.001$) and specificity (49% vs. 79% correspondingly, $p < 0.001$) were moderate, while the positive predictive value was only 5%. The performance of the early detection activity appears modest.

Uranium and radioactivity in drinking water and health

High natural uranium concentrations in water are found in wells drilled in bedrock in certain areas of Finland. We have studied drilled wells users in southern Finland. The drinking water and biological samples have been utilised in various studies concerning exposure, excretion, biological monitoring and the health effects of ingested uranium, which are described below.

Biological monitoring of uranium

Uranium can be measured from biological samples of people internally exposed to uranium. The study population consisted of 205 individuals living in 134 different households in southern Finland where drinking water is supplied from private drilled wells (Karpas et al. 2005a). The population included a broad range of uranium daily intakes from drinking water (0.03 – 2 775 $\mu g\ d^{-1}$). The uranium content in drinking water, urine, hair and toenails was determined by inductively coupled plasma mass spectrometry. The uranium content in all excretion pathways correlated with the uranium intake, particularly at elevated levels ($\geq 10\ \mu g\ d^{-1}$). Less than one per cent of ingested uranium is absorbed and most of the uranium is excreted in the faeces. In a continuous ingestion, uranium is excreted to urine and hair in about same amount (0.3%) and to lesser extent to toenails (0.04%). The source of uranium exposure was confirmed to be ingested water from drilled wells by comparing the $^{234}U/^{238}U$ ratio in water, hair, nails and urine samples of 45 study persons (Karpas et al. 2005b, 2006).

In order to predict uranium in human hair due to chronic exposure through drinking water, a compartment representing human hair was added to the uranium biokinetic model (Li et al. 2009). In the new model, excretion of uranium through urine is better represented when excretion to the hair compartment is accounted for. The model is applicable for chronic exposure as well as for an acute exposure incident.

In spite of high concentrations of natural uranium found in drinking water, no clear clinical symptoms have been observed among the exposed population (see below). The suspected low toxicity of Finnish bedrock water may be due to the predominance of two calcium-dependent species, $Ca_2UO_2(CO_3)_3(aq)$ and $CaUO_2(CO_3)_3{}^{2-}$, whose non-toxicity for cells has previously been described (Pratt et al. 2009).

Health effects of ingested uranium

Uranium accumulates in bone and when ingested it may increase the urinary excretion of calcium and phosphate, important components in the bone structure. Therefore, we studied 146 men and 142 women aged 26–83 years who for an average of 13 years had used drinking water originating from wells drilled in bedrock, in areas with a naturally high uranium content (Kurttio et al. 2005). Biochemical indicators of bone formation were serum osteocalcin and aminoterminal propeptide of type I procollagen, and a marker for bone resorption was serum type I collagen carboxy-terminal telopeptide (CTx). The median uranium concentration in drinking water was 27 μg/l (interquartile range 6–116 μg/l). There was some suggestion that elevation of CTx could be associated with increased uranium exposure in men, but no similar relationship was found in women. Thus, bone may be a target of the chemical toxicity of uranium in humans.

The renal effects of uranium exposure were measured in 95 men and 98 women aged 18 to 81 years who had used drinking water from drilled wells for an average of 16 years (Kurttio et al. 2006a). Several indicators of kidney cell toxicity and renal function as well as supine blood pressure were measured. The median uranium concentration in drinking water was 25 μg/l (interquartile range, 5–148 μg/l; maximum, 1 500 μg/l). Indicators of cytotoxicity and kidney function did not show evidence of renal damage. No statistically significant associations with uranium in urine, water, hair or toenails were found for 10 kidney toxicity indicators. Uranium exposure was associated with greater diastolic and systolic blood pressures, and the cumulative uranium intake was associated with increased glucose excretion in urine. To conclude, continuous uranium intake from drinking water, even at relatively high exposures, was not found to have irreversible cytotoxic effects on the kidneys in humans.

The association between osteopontin (OSTP) and uranium exposure was studied *in vitro*, in a human kidney cell model, and in the urine of exposed persons (Pratt et al. 2011). OSTP were monitored in the urine of uranium-exposed nuclear fuel industry workers and non-exposed persons from France, and in a chronically exposed population of drilled well users from Finland. In both approaches, OSTP secretion decreased when uranium exposure increased, which may be an indicator of the kidney effect. OSTP may thus be considered as a biomarker of uranium exposure together with other biomarkers.

Well water radioactivity and risk of cancers

Water from bedrock frequently contains higher concentrations of natural radionuclides than water from other sources. The subjects for the case–cohort study were selected from all drilled wells users in Finland (Auvinen et al. 2005, Kurttio et al. 2006b). The study comprised 88 stomach cancer, 61 bladder cancer and 51 kidney cancer cases diagnosed between 1981 and 1995, as well as a random sample of 274 reference persons, stratified by age and sex. Around 8% of the water samples from the drilled wells of the study persons exceeded the radon activity concentration of 1 000 Bq/l and 12% exceeded the WHO provisional guideline value of 15 μg/l for uranium. Even though ingested radionuclides from drinking water are a source of radiation exposure, they are not associated with a substantially increased risk of stomach, bladder or kidney cancers in concentrations occurring in drilled wells.

Nuclear power plants and cancers

To date, childhood leukaemia around nuclear installations has been investigated in many studies in other countries. An increased risk of leukaemia has been observed around some nuclear fuel reprocessing sites.

The majority of studies around nuclear power plants (NPPs) have not observed an increased risk of childhood leukaemia. However, a German study reported in 2008 an increased risk of leukaemia among young children (ages less than 5 years) living within a 5-km zone around NPPs. The Finnish study conducted by Heinävaara et al. (2010) was more comprehensive than the earlier studies, as it took into account residential history, i.e., the distances between the closest NPP and residencies (current and earlier, if relevant). In earlier studies, only the distance at diagnosis has been taken into account. The study investigated the leukaemia and total cancer incidence among children (aged less than 15 years) and adults living in the vicinity of NPPs in Finland. There are two NPPs in Finland: the Loviisa site started production in 1977 and the Olkiluoto site in 1979. A municipality was considered to be in the vicinity of an NPP if it had any area within 15 km of an NPP. The towns of Loviisa, Ruotsinpyhtää, Pernaja and Pyhtää were in the vicinity of Loviisa NPP and Eurajoki, Luvia and Rauma were in the vicinity of Olkiluoto NPP. At present, some 50 000 adults and 10 000 children are living in these municipalities. Approximately 100 people live permanently within the 5-km zone around an NPP. Childhood leukaemia is a rare disease with some 50 diagnoses per year. During the 30-year nuclear power era until the end of 2004, 16 children living in the vicinity of NPPs have been diagnosed with childhood leukaemia, while 15.9 cases were expected. Based on three alternative approaches, the risk of leukaemia and total cancer was not elevated among children living in the vicinity of NPPs. Leukaemia and total cancer were not associated with the residential distance from the NPP, either. The same conclusions hold for adults. The leukaemia incidence among children living in the vicinity of nuclear power plants (NPPs) did not differ from that in the rest of Finland. The leukemia and total cancer incidence were not associated with residential distance from the closest NPP, either.

Global fallout and cancers among reindeer herders

People in the Arctic regions, including the ingenious Sami people (Lapps), are one of the populations most heavily exposed to the global fallout from atmospheric atomic bomb testing in the 1950s and 1960s due to their diet rich in reindeer meat, in which radionuclides accumulate. We estimated the effect of the radioactive fallout and ethnicity on the cancer incidence in Northern Finland (Kurttio et al. 2010). A cohort of the Arctic population in Finland (n = 34 653) was identified through the Population Register Centre with grouping according to reindeer herding status, ethnicity and radiation exposure. The annual average radiation doses, based on ^{137}Cs whole-body measurements, were assigned according to birth year, gender and reindeer herder status. Incident cancer cases of *a priori* selected cancer types in the study cohort during 1971–2005 were identified from the Finnish Cancer Registry. A total of 2 630 cancer cases were observed versus 3 073 expected on the basis of incidence rates in Northern Finland (the standardised incidence ratio (SIR) was 0.86 with 95% CI of 0.82–0.89). For the indigenous Sami people, the SIR was even lower, 0.60 (95% CI 0.50–0.71). None of the sites with cancer cases was significantly associated with the lifetime cumulative radiation dose. The SIR for the combined group of radiation-related cancer sites increased with the cumulative radiation dose received before 15 years of age ($p = 0.004$). Despite the low overall cancer incidence in the Arctic population and ethnic Sami people in Finland, and the lack of association between the lifetime cumulative radiation exposure from global radioactive fallout and cancer incidence, we found some indication of an increased cancer risk associated with radiation exposure received during childhood. Potential underestimation and misclassification of the radiation dose may affect the results and the findings should be interpreted with caution.

Chernobyl accident and cancers

STUK participated in an evaluation of the impact of the Chernobyl nuclear power plant accident on the global burden of human cancers in Europe (Drozdovitch et al. 2007). In this study, radiation doses in 40 European countries were estimated. The average individual doses to the thyroid from the intake of ^{131}I for children aged 1 y were found to vary from 0.01 mGy in Portugal up to 750 mGy in Gomel Oblast (Belarus). The estimated childhood thyroid dose in Finland was 1 mGy. The average individual effective doses from external exposure and ingestion of long-lived radiocaesium accrued in the period 1986–2005 varied from 0 in Portugal to 10 mSv in Gomel Oblast and Bryansk Oblast (Russia). The estimated adult effective dose in Finland was 1.4 mSv. The uncertainties in the dose estimates were estimated on the basis of the availability and reliability of the radiation data that were used for dose reconstruction in each country.

Outside of Ukraine, Belarus and Russia, Finland was among the countries most heavily affected by the radioactive fallout from Chernobyl. Studies on the possible cancer effect of the fallout are needed scientifically to improve and testing risk models, and from a public health perspective to meet the information needs of the public. We assessed whether radioactive fallout from the Chernobyl accident influenced the thyroid cancer incidence among children and adolescents in Finland (But et al. 2006). The population was divided into two: those with thyroid doses less than 0.6 mSv and above 0.6 mSv. The cumulative incidence of thyroid cancer (n = 479) was identified from the Finnish Cancer Registry from a population aged 0–20 years in 1986 with a total of 1 356 801 persons. No clear difference in underlying thyroid cancer incidences rates were found during the pre- Chernobyl period (1970–1985) (rate ratio RR 0.95, 95% CI 0.81–1.10). During the post-Chernobyl period (1991–2003), the thyroid cancer incidence was lower in the more exposed population than in the less exposed population (RR 0.76, 95% CI 0.59–0.98). The results did not indicate any increase in thyroid cancer incidence related to exposure to radiation from the Chernobyl accident.

6.2.4 Occupational radiation and health

Cancer risk among Baltic Chernobyl cleanup workers

Two cohorts of Chernobyl cleanup workers from Estonia (4 786 men) and Latvia (5 546 men) were followed from 1986 to 1998 to investigate the cancer incidence among persons exposed to ionising radiation from the Chernobyl accident (Rahu et al. 2006). Each cohort was identified from various independent sources and followed using nationwide population and mortality registries. Cancers were ascertained by linkage with nationwide cancer registries. Overall, 75 incident cancers were identified in the Estonian cohort and 80 in the Latvian cohort. The combined-cohort SIR for all cancers was 1.15 (95% CI 0.98–1.34) and for leukaemia, 1.53 (95% CI 0.62–3.17; n = 7). Statistically significant excess cases of thyroid (SIR 7.06, 95% CI 2.84–14.55; n = 7) and brain cancer (SIR 2.14, 95% CI 1.07–3.83; n = 11) were found, mainly based on Latvian data. However, there was no evidence of a dose response for any of these sites, and the relationship with radiation exposure remains to be established. The observed excess of thyroid cancer cases may have been due to screening, the leukaemia cases included 2 unconfirmed diagnoses, and the excess cases of brain tumours may have been a chance finding. There was an indication of increased risk associated with early entry to the Chernobyl area and late follow-up, though not statistically significant.

Radiation exposure and health among nuclear workers

An international collaborative study on 407 391 nuclear industry workers was conducted in 15 countries to provide direct estimates of the cancer risk following protracted low doses of ionising radiation (Cardis et al. 2005). The Finnish contribution was a cohort of 11 000 subjects. The excess relative risk (ERR) for cancers other than leukaemia was 0.97 per Sievert (Sv) (90% CI 0.16–1.71). As detailed information on lifestyle factors was not available, possible confounding by smoking could not be ruled out, although adjustment for education was used. The ERR for leukaemia, excluding chronic lymphocytic leukemia (CLL), was 1.93 per Sv (90% CI < 0, 7.14). Based on these estimates, 1 to 2% of cancer deaths among workers in this cohort may be attributable to radiation. The results from this very large collaborative study suggest a somewhat higher risk than those in previous major studies, although they remain compatible, for instance, with studies on atomic bomb survivors. The findings indicate a small but detectable cancer risk at the low doses and dose rates received through occupational exposure. Due to differences in study approaches, direct comparison, for instance, with the Japanese Life Span Study is not possible for estimation of the DDREF.

Further detailed analysis of the 31 primary sites showed a significant association of occupational radiation exposure with lung cancer (p-value = 0.009; 1 457 deaths) and a borderline significant association for multiple myeloma (p = 0.058, 83 deaths) and ill-defined and secondary cancers (p = 0.056, 328 deaths) (Cardis et al. 2007b).

A separate analysis was conducted to assess the possible association of CLL with radiation exposure, which has been suggested in some studies (Vrijheid et al. 2007a). The relative risk (RR) at an occupational dose of 100 mSv compared to 0 mSv was 0.84 (95% CI 0.39–1.48) with a 10-year lag period. Different lag periods gave consistent results, but analyses of longer lag periods included very small numbers of cases with higher doses. The findings do not provide evidence of an association between low doses of external ionising radiation and CLL mortality, although the statistical power for long lag periods was limited.

The association of radiation with mortality from other diseases than cancer was also evaluated in the 13-country study (Vrijheid et al. 2007b). The ERR per Sv was 0.24 (95% CI 0.23–0.78) for mortality from all non-cancer diseases and 0.09 (95% CI 0.43–0.70) for circulatory diseases. Higher risk estimates were found for deaths from respiratory and digestive diseases, but the confidence intervals included zero. Increased risks were observed among younger workers (attained age <50 years) for all non-cancer causes of death, including external causes. It is unclear, therefore, whether these findings reflect real effects of radiation, random variation or residual confounding.

Cosmic radiation exposure and cancers among cabin crew

Earlier studies have found an increased breast cancer risk among female cabin crew. This has been suggested to reflect lifestyle factors (for example, age at first birth), other confounding factors (for example, age at menarche), or occupational factors such as exposure to cosmic radiation and circadian rhythm alterations due to repeated jet lag. The aim of a study by Kojo et al. (2005) was to assess the contribution of occupational versus lifestyle and other factors to the breast cancer risk among cabin attendants in Finland. A standardised self-administered questionnaire on demographic, occupational and lifestyle factors was given to 1 041 cabin attendants. A total of 27 breast cancer cases and 517 non-cases completed the questionnaire. Breast cancer diagnoses were confirmed through the Finnish Cancer Registry. Exposure to cosmic radiation was estimated based on self-reported flight history and timetables. A conditional logistic regression model was used for analysis. In the univariate analysis, a family history of breast cancer (OR = 2.67, 95% CI 1.00–7.08) was the strongest determinant of breast cancer. Of occupational exposures, sleep rhythm disruptions (OR = 1.72, 95% CI 0.70–4.27) were positively related and disruption of menstrual cycles (OR = 0.71, 95% CI 0.26–1.96) negatively related to breast cancer. However, both associations were statistically non-significant. The cumulative radiation dose (OR = 0.99, 95% CI 0.83–1.19) showed no effect on breast cancer. The results suggest that the breast cancer risk among Finnish cabin attendants is related to well-established risk factors of breast cancer, such as a family history of breast cancer. There was no clear evidence that the three occupational factors studied affected the breast cancer risk among Finnish flight attendants.

Cancer incidence among physicians occupationally exposed to radiation

Few studies have assessed the effect of occupational exposure to ionising radiation and cancer risk among physicians. Furthermore, previous studies have lacked individual radiation doses and they have evaluated cancer mortality rather than incidence. We identified a nationwide cohort of 1 312 physicians (radiologists, surgeons, cardiologists, intervention radiologists, oncologists and physicians of other specialties) from the dose registry maintained by STUK, providing radiation exposure data for 1970–2001 based on individual dosimeters (typically worn outside the lead apron) (Jartti et al. 2006). Never-monitored Finnish physicians (n = 15 821) were used as a reference group, identified from census data by Statistics Finland. Incident cancer cases were identified by record linkage with the Finnish Cancer Registry. The cumulative radiation doses exceeding the recording level (0.3–3.0 mSv during a three-month monitoring period or 0.1 mSv per one month monitoring period) were found for 1 029 physicians (59.8%). Six per cent of the radiologists had received a cumulative dose of 50 mSv or more. Compared to the general population, a slightly higher cancer incidence was found among female physicians both with (SIR 1.7; 95% CI 0.91–2.9) and without radiation exposure (1.2, 1.12–1.35). An increased risk of breast cancer (rate ratio RR = 1.7, 1.0–3.1) and melanoma (RR = 4.2; 95% CI 1.3–14.2) was found among female physicians working with radiation compared with other physicians. An elevated risk of leukaemia (RR = 5.5; 95% CI 1.2–25.9; based on two cases) was found in male, but not female physicians with radiation exposure. The results from a nationwide cohort suggest that occupational exposure to medical radiation is a minor risk factor for cancer among physicians, as no excess risk could be demonstrated even after a follow-up of up to 30 years.

Lens opacities among physicians occupationally exposed to radiation

A pilot study was carried out to assess the prevalence of lens opacities in physicians occupationally exposed to radiation and its possible relation to occupational factors, as well as to evaluate the feasibility of a larger study for risk assessment (Mrena et al. 2011). We identified all physicians monitored for radiation exposure aged 45–70 years, with a cumulative recorded radiation dose >10 mSv, and a monitoring period >15 years from the nationwide dose registry maintained by STUK. Out of 1312 eligible physicians, 120 were invited to participate and 59 (49%) consented. A full ophthalmological examination was performed and lenticular changes were graded using the Lens Opacities Classification System, version II (LOCS II). Of the 57 physicians without prior cataract, cortical opacities were found in 7% (95% CI 2–19) and posterior subcapsular in 5% (95% CI 1–15). The prevalence of lens opacities increased as a function of the cumulative recorded radiation dose, but the relationship was not statistically significant after controlling for age, sex and smoking (excess odds ratio for any lens opacity was 0.14 (95% CI –0.06, +0.20) per 10 mSv of cumulative radiation dose). Interventional radiologists and cardiologists had a higher prevalence of cortical and posterior lens opacities than the other physicians. The study is being expanded to cover another exposed group of 50 intervention radiologists or cardiologists, as well as an unexposed group of physicians.

6.2.5 Medical radiation and health

Computerised tomography and childhood cancer
STUK participated in the pilot phase of a study evaluating the feasibility of setting up cohorts of children examined with computerised tomography (CT). Contacts were established with the university hospitals, the frequencies of paediatric CT scans were estimated and the most common procedures and indications recorded. The radiology databases are centred around examinations rather than patients, and obtaining patient information turned out to be labour-intensive, particularly for systems prior to PACS (introduced around 2000). Information on earlier examinations has to be abstracted from the medical records, which increases the costs and diminishes the cohort size.

Mass screening of breast cancer
A study was carried out aimed at predicting the future cancer burden due to breast cancer. As breast cancer is subject to mass screening, the study also investigated the effect of mass screening and alternative mass screening scenarios on breast cancer. A population-based early detection programme for breast cancer has been in progress in Finland since 1987. According to the regulations during the study period (1987–2001), free-of-charge mammography screening was offered every second year to women aged 50–59 years. The attendance of mass screening resulted an increased incidence of localised breast cancer in the screening years and a decreased incidence in the non-screening years. The incidence peak was highest in the first screening round. The incidence of non-localised breast cancer only increased in the screening year of the first screening round (Seppänen et al. 2006b).

It was expected that after the screening programme the breast cancer incidence among those screened would be lower than that among the non-screened. However, this expected protective effect of screening was only observed among those aged 60–69 years and diagnosed with non-localised breast cancer. Widening of the screening programme to other age groups would increase the incidence of localised breast cancer, especially if age groups 50–69 years were included, but would have only a minor effect on the incidence of non-localised breast cancer (Seppänen et al. 2006a).

Possible changes in the mass screening programme in 2003 would have a minor effect on breast cancer mortality by 2012. If the mass screening programme had been extended to the age group 50–69 years, the breast cancer mortality among 40- to 74-year-old women would have decreased at most by 3% when compared to the current mass screening programme (Seppänen et al. 2008a). The methodology developed for this study could be used in predicting the future cancer burden due to other cancers subject to screening (for example cancers of the colon, cervix and prostate).

Radioiodine treatment for hyperthyroidism and risk of cancers and cardiovascular diseases

A cohort of approximately 2 800 patients treated with radioiodine for hyperthyroidism at Tampere University Hospital in 1968–2002 has been established and followed up for cancer incidence and mortality (Metso et al. 2007a). A reference cohort of similar size was constructed, with matching by age and sex. An increased cancer incidence was found in the patients treated with radioiodine (RR = 1.3), mainly based on oesophagus, breast and kidney cancer. Furthermore, the amount of radioiodine administered was correlated with the risk. A corresponding increase in cancer mortality was also recorded (RR = 1.3), with an excess of gastric and oesophageal cancer deaths (Metso et al. 2007b). In addition, a significantly increased death rate was observed for cardiovascular disease, in particular cerebrovascular and endocardial diseases. In an analysis of the hospital discharge registry data, hospitalisations for cardiovascular disease were more common for the patients than the control group (Metso et al. 2008). This was thought to reflect the effect of the underlying endocrine disorder rather than the radioiodine treatment, as in cancers.

Radiotherapy and secondary sarcoma

Radiotherapy is commonly used for the treatment of malignant disease. As a consequence of radiotherapy, an increased risk of developing a second malignant neoplasm has been shown. However, little is known about the effects of radiation on developing sarcomas. A very large nationwide cohort study was conducted to examine the risk of developing a bone or soft tissue sarcoma after radiotherapy for a first primary cancer (Virtanen et al. 2006). The study population included all the patients with primary cancers of the breast, cervix uteri, corpus uteri, lung, ovary, prostate, rectum and lymphoma diagnosed during 1953–2000 and identified from the Finnish Cancer Registry. Patients were followed up for subsequent sarcomas. The follow-up yielded 1.5 million person-years at risk and 147 sarcomas occurred. Compared to the national incidence rates, after 10 years of follow-up the sarcoma risk was increased among patients who had received neither radiotherapy nor chemotherapy (SIR 2.0, 95% CI 1.3–3.0), radiotherapy without chemotherapy (SIR 3.2, 95% CI 2.3–4.3), chemotherapy without radiotherapy (SIR 4.9, 95% CI 1.0–14.4), as well as combined radiotherapy and chemotherapy (SIR 3.4, 95% CI 0.4–12.5). For radiotherapy in ages below 55 the SIR was 4.2 (95% CI 2.9–5.8). In the adjusted regression analysis the rate ratio was 1.5 (95% CI 0.9–2.6) for the radiotherapy group. In conclusion, radiotherapy appears to be associated with an increased risk of developing sarcoma, especially among younger patients. Further investigation is needed to clarify the dose–response of the preceding ionising radiation.

In a subsequent analysis only angiosarcomas of the trunk (not considered above) were considered. In the follow-up of 1.8 million person-years at risk, 19 angiosarcomas developed, all after breast or gynaecological cancer. An excess of angiosarcomas over national incidence rates was observed among patients receiving radiotherapy without chemotherapy (SIR 6.0, 95% CI 2.7–11), both radiotherapy and chemotherapy (SIR 100, 95% CI 12–360), and other treatments (SIR 3.6, 95% CI 1.6–7.1). In regression analysis, however, the adjusted rate ratio for radiotherapy was 1.0 (95% CI 0.23–4.4). Although an increased risk of angiosarcoma among cancer patients is evident, especially with breast and gynaecological cancer, the excess does not appear to be strongly related to radiotherapy.

6.2.6 Mobile phone radiation and health

STUK participates in the recognised committees of the EU Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) and the Swedish Radiation Safety Authority (SSM) Independent Expert Group on Electromagnetic Fields, which have regularly assessed research on the health effects of mobile phone use.

INTERPHONE study

A total of 35 publications have appeared with authors from STUK from the INTERPHONE project. The results of the full Interphone material regarding the glioma and meningioma risk (Cardis et al. (INTERPHONE Study Group), 2010) as well as acoustic neuroma risk in relation to mobile phone use have been published. In an addition, several validation studies have been published (Vrijheid et al. 2006, Vrijheid et al. 2009b) besides a design paper (Cardis et al. 2007a). Incidence trends of brain tumours in the Nordic countries have been analysed in smaller scale collaboration (Klaeboe et al. 2005, Deltour et al. 2009, Larjavaara et al. Submitted, Deltour et al. Submitted). The possible effect of mobile phone use was also assessed in analyses of the material from the Nordic countries and UK (Schoemaker et al. 2005, Lahkola et al. 2007, 2008). Other related publications include two validation studies (Lahkola et al. 2005, Tokola et al. 2008), two meta-analyses (Lahkola et al. 2006, Repacholi et al. Submitted), three papers on the location of gliomas (Larjavaara et al. 2007, 2011; Hartikka et al. 2009). In addition, several studies on genetic factors (Bethke et al. 2008a, 2008b, 2008c, 2008d, 2009; Schwartzbaum et al. 2007a, 2007b; Kiuru et al. 2008, Malmer et al. 2007, Andersson et al. 2009, 2010) and other risk factors for brain tumours have been published (Schoemaker et al. 2006, 2010; Wigertz et al. 2007, 2008; Korhonen et al. 2010, Korhonen et al. Submitted).

The INTERPHONE study was an interview-based case–control study with 2 708 glioma and 2 409 meningioma cases and matched controls conducted in 13 countries using a common protocol (INTERPHONE Study Group 2010). The study was coordinated by the International Agency for Research on Cancer (IARC). A reduced odds ratio (OR) related to ever having been a regular mobile phone user was seen for glioma [OR 0.81; 95% CI 0.70–0.94] and meningioma (OR 0.79; 95% CI 0.68–0.91), possibly reflecting participation bias or other methodological limitations. No elevated OR was observed 10 years after first phone use (glioma: OR 0.98; 95% CI 0.76–1.26; meningioma: OR 0.83; 95% CI 0.61–1.14). ORs were <1.0 for all deciles of the lifetime number of phone calls and nine deciles of the cumulative call time. In the 10th decile of recalled cumulative call time, 1 640 h, the OR was 1.40 (95% CI 1.03–1.89) for glioma, and 1.15 (95% CI 0.81–1.62) for meningioma; however, there were implausible values of reported use in this group. ORs for glioma tended to be greater in the temporal lobe than in other lobes of the brain, but the CIs around the lobe-specific estimates were wide. ORs for glioma tended to be greater in subjects who reported usual phone use on the same side of the head as their tumour rather than on the opposite side. Overall, no increase in the risk of glioma or meningioma was observed with the use of mobile phones. There were suggestions of an increased risk of glioma at the highest exposure levels, but biases and error prevent a causal interpretation. The possible effects of long-term heavy use of mobile phones require further investigation.

The effect of mobile phone use on the risk of brain tumours, particularly gliomas and meningiomas as well as acoustic neuromas, was evaluated using both a case-control approach and a meta-analysis in the PhD thesis by Lahkola in 2010. In addition, selection bias due to differential participation was assessed. The risk of glioma and meningioma in relation to mobile phone use was investigated in population-based case-control studies conducted in five North European countries. All these countries used a common protocol and were included in the INTERPHONE study. Cases (1 521 gliomas and 1 209 meningiomas) were mostly identified from hospitals and controls (3 299) from national population registers or general practitioners' patient lists. A detailed history of mobile phone use was obtained in personal interviews. Mobile phone use was assessed using several exposure indicators, such as regular use, duration of use as well as the cumulative number of hours and calls. Mobile phone use was not conclusively related to an increased risk of either glioma or meningioma. For both tumour types, the risk was decreased among regular mobile phone users compared to never and non-regular users (OR = 0.78, 95% CI: 0.68–0.91 for gliomas, OR = 0.76, 95% CI: 0.65–0.89 for meningiomas) (Lahkola et al. 2007, 2008). According to the 12 studies included in the meta-analysis, the pooled estimate for all tumour types combined did not show an association between mobile phone use and brain tumours (OR = 0.98, 95% CI: 0.83–1.16) (Lahkola et al. 2006). Nor was much evidence of increased risk found in the analyses according to tumour type, telephone type or tumour location. In the Finnish INTERPHONE study, an indication of selection bias was detected, as the risk for brain tumours related to mobile phone use was lower among study participants than in the group that also included the subjects who refused to grant a full interview but responded to the short questionnaire (Lahkola et al. 2005). Selection bias may also have distorted the results of the five-country case-control studies. In conclusion, the studies do not suggest mobile phone use as a cause of brain tumours. As there were decreased risks in the case-control studies, the possibility that the results are affected by bias needs to be carefully considered in their interpretation.

Health of mobile phone users – a pilot study

The feasibility of the prospective cohort study COSMOS was assessed in a pilot study (Heinävaara et al. 2011) that investigated whether COSMOS could be executed according to the international COSMOS study plan. At the same time, possible risk factors were explored. The pilot study was also used to evaluate whether the length of the questionnaire (short vs. long) and the recruitment approach (one- vs. two phase strategy) affected the response rate. Furthermore, the pilot study was used for the validation of exposure assessment. The pilot study demonstrated that the COSMOS study is feasible in Finland. The cohort of mobile phone users could be recruited from samples of network operators' customers so that the sampling is stratified with respect to age, sex and the level of mobile phone use. Mobile phone data were obtained from operators for those who agreed to participate in the study. Neither the length of the questionnaire nor the recruitment approach affected the response rate. Therefore, the planned recruitment strategy, the less expensive one in two phases, will be used. The largest risk of failure is likely to be due to a low response rate (<20%), which increases the recruitment cost and prolongs the recruitment time. In the analysis of exposure assessment, the agreement between self-reported and operator-derived estimates of call time was found to be moderate and overestimation of the call time to be common.

An international cohort study of mobile phone users and health

A cohort of Finnish mobile phone users is being established as a part of an international collaborative study known with acronym COSMOS. The study invitations are being sent to private mobile phone users who are aged between 18 and 69 years in three consecutive years (2009–2011). The study invitations are being sent to samples of customers of the network operators Elisa and TeliaSonera in two phases. The informed consent forms are being sent first with the invitation letter followed by the paper questionnaire if a study subject returns the signed informed consent form but has not answered the questionnaire on the Internet. In the first recruitment round in 2009, 33 180 invitations were sent. Some 12% of study participants returned the signed informed consent form and 10% returned the signed consent form and answered the questionnaire (~2/3 used the paper questionnaire). In the second recruitment round in 2010, some 76 200 invitations were sent. The corresponding percentages in this round are, at present, 11% and 9%, respectively. The recruitment practice was slightly modified from the first round to another to be as cost effective as possible. Further modifications are likely in the third round. The international collaborative cohort study on the health of mobile phone users is described in detail in Schüz et al. (2010). The study is currently also ongoing in Denmark, Sweden, the UK and the Netherlands. The aim is to recruit a cohort of 250 000 mobile phone users who will be followed for at least 25 years. Information on mobile phone use is being collected prospectively through a questionnaire and objective traffic data from network operators. The association with disease risks will be examined by linking cohort members to existing disease registries, while changes in symptoms such as headache and sleep quality and of well-being are being assessed using baseline and follow-up questionnaires.

A prospective cohort study conducted with appropriate diligence and a sufficient sample size overcomes many of the shortcomings of previous studies. Its major advantages are exposure assessment prior to the diagnosis of disease, the prospective collection of objective exposure information, long-term follow-up of multiple health outcomes, and the flexibility to investigate future changes in technologies or new research questions.

6.2.7 Aetiology of brain tumours

Brain tumour incidence trends

Brain tumour incidence trends in four Nordic countries were evaluated to assess whether a change in trends has taken place since mobile phone use became widespread in these populations (Deltour et al. 2009).

Time trends in annual incidence rates among men and women aged 20 to 79 years were modelled using joinpoint regression. No clear changes of the long-term trends were detected in the most recent period (1998–2003) for gliomas or meningiomas. Up to 2003, the findings did not indicate any observable increase that could be associated with an effect of mobile phone use, as incidence rates were either stable, decreasing or continued a gradual increase that started before their introduction. Hence, either there is no risk or it is too small to be observed, is restricted to subgroups of brain tumours or users, or the induction period is longer than 10 years.

An important recent contribution is a case-case analysis of 800 gliomas examining the distance from the tumour midpoint to the typical position of the mobile phone while used (line between external orifice of the ear and corner of the mouth) (Larjavaara et al. 2011a). The analysis demonstrated that tumours were located closest to the source of exposure among never-regular and contralateral users, although not statistically significantly. In the case-specular analysis, the mean distances between exposure source and location were similar for cases and speculars (hypothetical locations assigned to each case as a mirror image of the observed mid-point in the 3D coordinates of the brain). These findings do not suggest that gliomas in phone users are preferentially located in the parts of the brain with the highest RF fields from mobile phones.

Table III. Existence of possible associations between single nucleotide polymorphisms (SNPs) and other genetic variants and the risk of developing a brain tumour explored during the INTERPHONE project.

Brain cancer type	Gene (SNP)	OR (95% CI)	Reference
Glioblastoma	p53 (rs1625895)	0.53 (0.36 – 0.79)	Malmer et al. 2007
Meningioma	ATM (rs228599)	0.74 (0.58 – 0.94)	Malmer et al. 2007
Meningioma	ATM (rs664143)	0.75 (0.59 – 0.95)	Malmer et al. 2007
Glioma	GSTP1 (105Val/114Ala)	0.73 (0.54 – 0.99)	Schwartzbaum et al 2007
Glioma	XRCC1 (rs25487) + XRCC3 (rs861539)	3.18 (1.26 – 8.04	Kiuru et al. 2008
Meningioma	XRCC1 (rs25487) + XRCC3 (rs861539)	2.99 (1.16 – 7.72)	Kiuru et al. 2008
Glioma	CHAF1A (rs243356)	1.32 (1.14 – 1.54)	Bethke et al. 2008b
Meningioma	BRIP-1 (rs4968451)	1.57 (1.28 – 1.93)	Bethke et al. 2008a
Glioma	CASP8 (rs1045485)	1.37 (1.10 – 1.70)	Bethke et al. 2008c
Meningioma	CASP8 (rs1045485)	no association	Bethke et al. 2009
Meningiona	MTHFR (rs1801131 + rs180113)	2.11 (1.42 – 3.12)	Bethke et al. 2008d
Meningioma	MTRR (rs1801394)	1.44 (1.02 – 1.94)	Bethke et al. 2008d
Glioma, meningioma	MNS16A minisatellite	no association	Andersson et al. 2009
Glioblastoma	EGFR (rs4947986)	1.42 (1.06 – 1.91)	Andersson et al. 2010
Glioma	RTEL1 (rs6010620)	0.70 (0.50 – 0.99)	Schoemaker et al. 2010
Glioma	PHLDB1 (rs498872)	0.53 (0.32 – 0.89)	Schoemaker et al. 2010

Genetic factors and brain tumour risk

In addition to mobile phone use, possible associations between single nucleotide polymorphisms (SNPs) and the risk of developing a brain tumour were explored in the INTERPHONE study. Blood samples from four case-control series were assembled in Denmark, Finland, Sweden, and the United Kingdom. A number of genetic polymorphisms of xenobiotic metabolism, DNA repair, folate metabolism, apoptosis, replication proteins and transcription factors were genotyped from DNA samples obtained from 701 glioma cases, 528 meningioma cases, and 1 589 controls. We detected both positive and negative associations for several polymorphic loci and glioma and meningioma (see Table III). In conclusion, our results indicated that genomic variants and especially some of their combinations may have an impact on the risk of adult brain cancer.

6.3 Use of radiation

6.3.1 Medical use of radiation

The SENTINEL project

SENTINEL (Safety and efficacy for new techniques and imaging using new equipment to support European legislation), a project related to the diagnostic use of radiation, was launched in 2005 and was co-funded by the European Union. SENTINEL aimed to have a particular emphasis on frequent examinations, high-dose procedures and sensitive groups. The project comprised eight work modules covering nearly the entire field of the diagnostic use of radiation, with the exception of computed tomography. STUK was primarily involved in the following subject areas:

- performance standards/mathematical assessment of fluoroscopic image quality
- cardiology/collation of patient doses in cardiac studies
- interventional radiology/collation of patient doses in interventional radiology
- personnel doses in interventional radiology
- mammography examinations.

Follow-up research into patient and personnel doses in interventional radiology began in 2005 (Kosunen et al. 2005). Provisional results were obtained on patient doses in interventional radiology. A review of individual doses of persons working in interventional radiology and cardiology was also conducted. A STUK-A report on the relationships between physical measurements and user evaluation of image quality in medical radiology was published in 2006 (Tapiovaara 2006, see also Tapiovaara 2005 and 2008).

A conference on special issues in paediatric X-ray examinations was arranged at STUK. In 2007 the project compiled a summary of interventional radiology patient doses (Vano et al. 2008). A review of the doses to interventional radiologists and cardiologists was also carried out. The methods to estimate the patient dose in interventional radiology were evaluated and published (Kosunen et al. 2005). The project also resulted in some other publications, e.g. European survey on patient doses in paediatric radiology (Smans et al. 2008b).

Improved optimisation of the use of computed tomography equipment

The annual number of computed tomography (CT) examinations has steadily risen and new examination applications have been found along with the development of CT equipment. Even though CT examinations constituted only about 8% of all X-ray examinations in 2008, they caused about 58% of the total effective dose to the patients from all X-ray diagnostics. The quality criteria and reference levels issued by the European Union are partially out of date, and the establishment of protocols for new multi-slice scanners, i.e., the balancing of image quality and dose, has often laid too much emphasis on good image quality. In order to improve the situation in Finland, a project was launched to study the clinical use of CT scanners in Finland.

The aims of the research project were:

- to prepare recommendations for improving the setup of the examination protocol
- to update the diagnostic reference levels (DRL) for doses in CT examinations and to issue DRLs for paediatric examinations
- to develop a suitable routine inspection method
- to update the quality control guide for CT scanners.

A practical method ("cradle method") to measure the DLP and $CTDI_{vol}$ in various examinations was developed (Karppinen and Järvinen 2006a, Merimaa et al. 2010). The measurements for a large number of CT scanners (about 80% of the total number) indicated that the doses are generally higher for multi-slice than for single-slice scanners. Differences were found between DLP values at various hospitals that suggest a need for better optimisation of examination protocols. The measured doses were not in line with the current DRLs. The final report of the research project was published in 2006 (Karppinen and Järvinen 2006b). The DRLs for CT examinations were revised on the basis of these findings in 2007. A summary compiled from quality assurance work was used in preparing a new guide for quality control methods in X-ray examinations in 2008. The method of measuring examination-specific doses used in the investigation has subsequently been applied in inspections of the use of radiation.

Dosimetry for diagnostic and interventional radiology: testing of the IAEA Code of Practice

STUK participates/has participated in two research projects co-ordinated by the IAEA (2006–2009: Implementation of the International Code of Practice on Dosimetry in Diagnostic Radiology and 2010–2013: The development of advanced dosimetry techniques for diagnostic and interventional radiology). The aim of these projects has been to evaluate the feasibility and accuracy of the methods described in the IAEA publication "Dosimetry in Diagnostic Radiology: An International Code of Practice" (IAEA TRS 457). This concerns both the calibrations of dosimeters and clinical dosimetry. The research group includes experts from calibration laboratories and hospitals from several countries.

In the first project (2006–2009) the implementation of TRS 457 was studied. STUK evaluated the protocol by comparing the methods of TRS 457 with those used in Finland, both at the standard dosimetry laboratory (calibrations) and at Finnish health care units (clinical dosimetry). STUK coordinated the part of the project dealing with the use and calibration of kerma-area product (KAP) meters. Comparisons of calibrations and measurements between project partners were also arranged.

The results of the project were published in the IAEA Health series. Results from research related to the calibration and use of KAP meters were also published in international journals (Toroi et al. 2008a, 2008b, Toroi and Kosunen 2010) and guidelines for Finnish users were provided in a technical report (Toroi et al. 2008c). These papers also formed part of a PhD thesis (Toroi 2009). Based on these studies, the new methods for KAP meter calibration were introduced internationally (Pöyry et al. 2006a, 2006b, Toroi and Kosunen 2010). The results have been used to improve the reliability of the calibration methods used by the standard dosimetry laboratory of STUK, the methods of measurement used in inspections, and also in the training of users of radiation.

In the second research project (2010–2013), the usefulness of TRS 457 methods for new challenging dosimetric situations will be reviewed, tested and evaluated. The research group includes experts from STUK for X-ray dosimetry and X-ray imaging, in addition to experts in clinical radiology physics from three Finnish university hospitals: Kuopio, Helsinki and Oulu. The international research group includes the IAEA and experts from 12 different countries.

This project has seven activities. STUK is taking part in all of the activities and is coordinating two of them. In the activity *interpretation of clinical dose* *data* the aim is to develop guidance on the methods of organ dose estimation for diagnostic radiology examinations, and the use of these in cancer risk estimation. A pilot questionnaire study on the calculation of organ doses and evaluation of the associated risk was performed during 2010. Another coordinated activity is *CT and modalities and methods not covered by TRS 457*. In this activity the aim is to develop, test and give dosimetry guidance for modalities that are not covered by the Code of Practice. This includes multi-slice CT systems, cone beam CT and digital tomosynthesis (3D mammography).

The expected result of this second project is to have generally more reliable dose measurements and computational methods as a basis for reliable surveys on patient doses. Based on the study, guidance to Finnish hospitals will be given. The results of the project will be published in the IAEA Health series. The results will also be published in scientific journals.

Comparison and development of dose measurements in mammography

To assess and improve the reliability of mammography dosimetry, the calibration and measurement methods and the properties of dose meters have been studied. The energy dependence of different meter types has been assessed within the energy range used in novel digital mammography systems. An internal report was written and, based on the study, new radiation qualities for calibrations were established and proper meter types were recommended to be used for inspections. A recommendation to shift from entrance surface dose (ESD) to mean glandular dose (MGD) was given and a national guide for dosimetry in mammography is under finalisation.

In addition, a new method to be used for dosimetry in digital mammography was investigated (Toroi et al. 2009). In mammography, part of the radiation beam always falls directly on the detector without attenuating tissue in its path. Our work assessed whether the pixel values from such a detector area could be used to monitor the radiation beam incident on the patient. The results were in agreement with the dose calculation based on X-ray tube voltage, filtration, tube charge and X-ray tube output measurements, the method generally used for this purpose. The recommended accuracy can be achieved with the studied method.

New evaluation of radiation qualities and required dose levels is needed when new image receptor types are introduced in mammography. In this work, the optimal selections were examined with a direct digital mammography detector (Toroi et al. 2007). For this device, the use of higher X-ray energies than had been used clinically earlier was recommended and appropriate image quality was achieved by increasing the (unacceptably low) dose level used in the imaging. This work was performed as a co-operation with the University Hospital of Leuven, during a six month researcher exchange period. During this period, research was also conducted on the optimisation of processing of raw image data and flat field correction in digital mammography (Zanca et al. 2006, 2007, Pöyry et al. 2006, Toroi et al. 2007).

These mammography studies also formed part of a PhD thesis (Toroi 2009).

Determination of patient doses at paediatric X-ray examinations

As, for a given dose, paediatric patients are subject to higher radiation risks than adults, they enjoy a special radiation protection status. The aim of the project was to set patient dose reference levels for the most common paediatric X-ray examinations and to determine organ doses and effective doses in paediatric imaging. In addition, a study of practices was conducted by comparing imaging protocols (technique factors) and patient doses. Comparative information on paediatric examination protocols and patient doses in radiography examinations of the skull, sinus, chest, abdomen and pelvis were collected. Altogether, 24 Finnish hospitals were asked to register paediatric examination data, including patient information and examination parameters and specifications. The total number of examinations in the study was 1916 (1426 chest, 228 sinus, 96 abdominal, 94 skull and 72 pelvic examinations). Entrance surface dose (ESD) and dose-area products (DAP) were calculated retrospectively or DAP meters were used. Organ doses and effective doses were determined using a Monte Carlo program (PCXMC).

The results revealed considerable variation in examination protocols between different hospitals, causing large variations in patient doses. Mean effective doses of different age groups ranged from 5 μSv to 14 μSv in skull and sinus examinations, from 25 μSv to 483 μSv in abdominal examinations, and from 6 μSv to 48 μSv in chest examinations. In chest and sinus examinations, the amount of data was extensive, allowing national paediatric diagnostic reference levels to be defined. Parameter selection in paediatric examination protocols should be harmonised in order to reduce patient doses and improve optimisation.

The project findings have been published in three scientific articles (Kiljunen et al. 2005, 2006, 2007) and used in a doctoral thesis (Kiljunen 2008). STUK has set reference levels for three paediatric X-ray examinations based on the project findings. The project data were also used when two STUK bulletins on paediatric X-ray imaging were prepared.

Investigation of patient doses in paediatric CT examinations and the feasibility of setting diagnostic reference levels

Despite the fact that doses to paediatric patients from computed tomography (CT) examinations are of special concern, only few findings or studies on the setting of paediatric Diagnostic Reference Levels (DRLs) have been published. The aim of this study was to collect and compare patient dose data in paediatric CT examinations in order to conclude on the feasibility of setting DRLs for these examinations. Preliminary joint studies with the other Nordic countries revealed differences in the indications for CT examinations and in the scanning protocols between radiology departments, and a very high level of variation in patient dose data (Godske Friberg et al. 2008). The collection of further patient dose data, focused on a selection of the most common and important paediatric CT examinations, was considered necessary in order to conclude on the feasibility of setting the DRLs. The further study was focused on paediatric chest and head CT and was launched in collaboration with five university hospitals in Finland and with some hospitals from Estonia and Lithuania. The results were presented at the International Congress of Radiation Protection in Medicine, Varna 2010, and submitted for publication in Radiation Protection Dosimetry.

The data obtained were not considered sufficient to provide firm recommendations on DRLs. However, it was shown that for the DRLs, patient dose data from different CT scanners should be collected in age or weight groups, possibly for different indications. For practical reasons, the DRLs for paediatric *chest* CT should be given as a continuous DRL curve as a function of patient weight. For paediatric *head* CT, DRLs for a few age groups could be given. The users of the DRLs should know on which CT dosimetry phantom (16 cm or 32 cm diameter) the console indication of dose is based for different paediatric scanning protocols. The feasibility of DRLs should be re-evaluated every 2–3 years.

PCXMC: a program for calculating organ doses in X-ray examinations

In medical radiology, the air kerma at the patient entrance surface (ESD) and the dose-area product (DAP) are common patient dose descriptors that can be readily measured. However, they are not sufficient for evaluating the radiation risk from the X-ray examination or for comparing the radiation detriment from different examinations. Therefore, methods are needed for the calculation of conversion factors from ESD or DAP to the effective dose and doses in various organs.

In 1997, STUK published a PC program (PCXMC) that is capable of providing such data, calculated by the Monte Carlo method and utilising the mathematical phantoms of Cristy (1980). Since then, the program has been developed further. The program was updated to PCXMC 2.0 in 2008. The phantom models were improved to better suit external irradiation dose calculations, new organs were designed in the phantoms, the calculation of the effective dose was updated to use the ICRP 103 tissue weighting factors, and the program was extended to use the models of BEIR VII to calculate the cancer risk from the organ doses. The program documentation was published as report STUK-A231 (Tapiovaara and

Siiskonen 2008). In order to validate the program further, we also collaborated in a study where comparison calculations were made with the MCNP code and voxel phantoms representing premature babies (Smans et al. 2008a). The organ doses calculated with both methods were found to be in good agreement, given that the x-ray field covered the organs similarly in both calculations.

PCXMC is used in STUK for our own research, for estimating the effective doses related to actual patient dose measurements and for estimating foetal doses in pregnant patients. Program licences are also sold to other interested users. So far, more than 500 programs have been sold, more than 90% of them abroad. The program has been widely used in scientific work: there are numerous citations to the program in the scientific literature. The Internet pages describing the program can be found at *www.stuk.fi/pcxmc/*.

Review of relationships between physical measurements and user evaluation of image quality

There are many tasks in radiology departments that involve the assessment of image quality. Equipment purchasing is partly based on performance specifications, acceptance testing verifies that the system fulfils the specified performance criteria, constancy testing attempts to detect any changes in the imaging system, clinical testing concentrates on the fulfilment of clinical needs, and optimisation processes attempt to find the best ways to use the imaging system for clinical purposes. These different tasks are best performed by different assessment methods and the outcome is often referred to as technical (or physical) image quality or clinical image quality, according to the method used. Although establishing the link between physical image quality measures and clinical utility has been pursued for decades, the relationship between the results of physical measurements, phantom evaluations and clinical performance is not fully understood. A report (STUK-A219, Tapiovaara 2006) was written to discuss various assessment methods, to point out factors that may influence the interpretation of their results, and to review recent studies that had explored the relationships between them.

It was concluded that the various image quality evaluation tasks in an X-ray department still require different methods. Presently, exact physical measurements cannot supersede subjective evaluation in judging the acceptability of clinical images, whereas physical measurements are indispensable in specification, quality assurance and the testing of technical performance.

Surveys on the frequency of X-ray examinations and collective patient doses

The Medical Exposure Directive (MED 97/43/Euratom) and its implementation in national legislation (the Decree of the Ministry of Health and Social Affairs on the Medical Use of Radiation, 423/2000) calls for users of radiation to monitor the doses to patients in X-ray diagnostic and nuclear medicine examinations. Furthermore, the Member States shall ensure that the distribution of individual dose estimates from medical exposure is determined for the population and for relevant reference groups of the population. In Finland, STUK is responsible for collecting summaries of the frequencies of the radiological procedures and for estimating the doses to the population. The collective effective doses to the population from X-ray and nuclear medicine examinations have been estimated regularly in periods of a few years for over ten years.

STUK has collected the number of various radiological examinations, classified according to the examination type and to examinations made to adult and child patients in Finland in 2008 (Tenkanen-Rautakoski 2010). In 2008, approximately 3.9 million X-ray examinations were conducted in Finland, corresponding to about 717 examinations per 1 000 inhabitants. Dental examinations are excluded from this number, but CT examinations (ca. 60 per 1 000 inhabitants) and interventional X-ray procedures (ca. 5 per 1 000 inhabitants) are included. Compared to 2005, the number of X-ray examinations had slightly increased, although the average number of examinations per inhabitant had slightly decreased. The proportions of conventional X-ray examinations, computed tomography examinations, and angiographic and interventional procedures were ca. 90.2%, 8.3%, 0.8% and 0.8%, respectively. Slightly more than 0.5 million ultrasound examinations and 190 000 MRI examinations were reported.

Of all the X-ray examinations in 2008, ca. 7.5% were carried out on child patients (younger than 16 years), while child patients accounted for 8% of conventional X-ray examinations and 2% of computed tomography and angiographic examinations.

In another study, the collective effective doses to the population from X-ray and nuclear medicine examinations in Finland in 2008 and 2009, respectively, were estimated. The results were presented at the International Congress of Radiation Protection in Medicine, Varna 2010, and have been submitted for publication in Radiation Protection Dosimetry. A preliminary study based on 2005 data on examination frequencies was published earlier (Tenkanen-Rautakoski et al. 2008).

The estimated mean effective dose to the population was 0.45 mSv from X-ray examinations and 0.03 mSv from nuclear medicine examinations. These values have not changed substantially during the last ten years. However, the proportional dose due to CT examinations increased from 50% in 2005 to 58% in 2008 of the collective effective dose from all X-ray examinations, and proportional dose of PET examinations increased from 7% to 13% of the collective effective dose from nuclear medicine examinations.

Patient radiation exposure in measurements of bone mineral density

This thesis work developed measurement methods for determining the radiation exposure of the patient in dual energy X-ray absorptiometry (DEXA) measurements of bone mineral density and estimated the effective doses resulting from the use of various DEXA systems. The work was completed and a Master's thesis published in 2005 (Aallos 2005).

The doses arising from various DEXA systems differ due to various operating modes, differences in radiation quality and the variety of measurement programmes employed in them. Typically, the radiation exposure of the patient may be reduced by one third by optimising examinations and reducing the number of parts of the body selected for imaging. While the effective doses to patients were less than 0.5 μSv in measurements of the peripheral skeleton, the doses in measurements of the central skeleton typically varied between 0.4 and 26 μSv, depending on the scanner model. In one scanner (Lunar Expert) the dose was notably higher, 78 μSv.

Analysis of quality control data for modern radiotherapy linear accelerators

Quality control (QC) data for radiotherapy linear accelerators, collected by Helsinki University Central Hospital between 2000 and 2004, were analysed (Kapanen et al. 2006a). The goal was to provide information for the evaluation and elaboration of QC of accelerator outputs and to propose a method for QC data analysis. Short- and long-term drifts in outputs were quantified by fitting empirical mathematical models to the QC measurements. Normally, long-term drifts were well (≤ 1%) modelled by either a straight line or a single-exponential function. A drift of 2% occurred in 18 ± 12 months. The shortest drift times, for the drift of 2%, of only 2–3 months were observed for some new accelerators just after commissioning, but they stabilised during the first 2–3 years. The short-term reproducibility and the long-term stability of local constancy checks, carried out with a sealed plane parallel ion chamber, were also estimated by fitting empirical models to the QC measurements. The reproducibility was 0.2–0.5% depending on the positioning practice of the device. Long-term instabilities of about 0.3%/month were observed for some checking devices. The reproducibility of local absorbed dose measurements was estimated to be about 0.5%. The proposed empirical model fitting of QC data facilitates the recognition of erroneous QC measurements and abnormal output behaviour caused by malfunctions, offering a tool to improve dose control.

The results of this study were exploited in another study that investigated the influence of output measurement time interval and tolerance on treatment dose deviation in photon external beam radiotherapy (Kapanen et al. 2006b). A method was developed to estimate the spread of treatment doses due to a given output measurement, time interval and action level in external photon beam radiotherapy The method exploits empirical or simulated data of both output stability and the reproducibility of the absolute output measurements and relative constancy checks. The spread of an output and the probability that an output is outside the predefined tolerance limits were estimated for different quality control procedures of the output. The use of internationally recommended output measurement intervals of 3, 1 and 0.25 months together with an action level of ±2% results in a respective out-of-tolerance probability of up to 49%, 26% and 3%, while the output is kept within up to ±5.5%, ±4.0% and ±2.0%, respectively. It was also found that the action level has a more prominent relative influence than the measurement interval. The results suggest that similar treatment quality can be achieved by doubling the output measurement time interval and lowering the action level from ±2% to ±1.5% and the constancy check action level from ±3% to ±2%.

The results of the above two studies provided evidence-based data that have supported the decision making in the process of STUK's approval of QC programmes for accelerators.

Accuracy of central axis dose calculations for photon external radiotherapy

The accuracy of central axis dose calculation was evaluated for 48 photon beams from 28 linear accelerators at nine centres in Finland (Kapanen et al. 2008). In addition, inter-accelerator consistency of beam data was evaluated for Varian Clinac 600 CDs and 2100 CDs, and averaged data sets were generated for output factors (OFs) and percentage depth doses (PDDs). The averaged data sets obtained were used to identify potential dosimetry reasons for local errors.

Agreement between measured and calculated doses was determined at the isocentre at 10 cm depth in water for nine different-sized open square and rectangular fields. Averaged OFs were determined for nominal energies of 4, 6, 10, 15 and 18 MV both at dmax and at 10 cm depth. In order to develop a function for the OF data, OFs for square fields were parameterised through empirical model fitting. The feasibility of a simple equivalent square collimator formula was also evaluated for the presentation of OFs for rectangular fields. Averaged PDDs were determined at a depth of 10 cm.

The difference between measured and calculated doses exceeded ±3%, ±2% and ±1% for 3, 6 and 35 of the investigated 48 beams, respectively. The differences were due to errors observed in both OFs and depth–dose data. When the agreement between dose calculation and measurement was within ±1%, inter-accelerator differences in OFs were within ±1.0% at both the depth of dose maximum and at 10 cm for Clinac 600 CDs and also for 2100 CDs. Differences in PDDs were within ±1.2%.

The importance of quality control for beam data was demonstrated by showing significant errors in measured data. For Clinac 600 and 2100 CDs, the quality control can be accurately performed by comparing local data to averaged reference data. Robust averaged data sets were obtained for 6, 15 and 18 MV beams of Clinac 2100 CDs.

The results of this study have provided useful data for the analysis of the results of acceptance testing of accelerators.

European Metrology Research Programme (EMRP)

The European Metrology Research Programme (EMRP), available for National Metrology Laboratories and belonging to the Seventh European Framework Research Programme began in 2008. Several National Metrology Laboratories from Europe participated in the projects. STUK participated in two projects concerned with dosimetry in radiotherapy:

- JRP6 – Increasing cancer treatment efficacy using 3D brachytherapy
- JRP7 – External Beam Cancer Therapy.

The role of STUK in these projects was:

- Development of dosimetry and dose distribution verification methods for ^{191}Ir and ^{125}I brachytherapy sources using radiochromic and scintillation detectors, and for ^{125}I eye applicators using solid state detectors
- Development of dosimetry and dose distribution verification methods for intensity modulated radiotherapy (IMRT) of prostate cancer.

From the point of view of the role of STUK, JRP6 investigated the properties of dosimeters used in measurements, and in JRP7 a system for measurements of prostate cancer radiotherapy was created. A water-filled measurement phantom, used in both projects, was constructed at STUK in the final form in 2010. A wide range of detectors and anatomical structures can be installed in this phantom. Parallel to the development of the phantom, read-out systems for Gafchromic® EBT and EBT-2 radiochromic films have been constructed and the basic dosimetric characteristics of the films have been determined The findings of this work have been summarised in project reports, in international congress presentations (Sipilä et al. 2010), and will be the subject of some publications under preparation. Further details of the two projects are given in the following:

Development of methods for brachytherapy dosimetry (2008–2011)

The aim was to develop a suitable method (dosimeter and measurement phantom) for the verification of dose distributions in gynaecological treatments by ^{192}Ir and ophthalmic treatments by ^{125}I.

Small scintillation dosimeters, Gafchromic films and semiconductor detectors were applied in the measurements. As the first step, the energy and dose response of the selected detectors were determined for the energy region and dose rates of interest (up to 20 Gy/min) in X-ray and ^{60}Co gamma beams. As the second step, 2D and 3D dose distributions of ^{191}Ir and ^{125}I sources in a phantom were determined. For this purpose, a water phantom with appropriate source and detector holders was developed. Experimental measurements were compared with Monte Carlo simulations in selected cases.

The results suggest that the Gafchromic EBT film is sufficiently accurate for the determination of relative dose distributions of brachytherapy sources, while the strong energy dependence of diode and scintillation detectors makes them less feasible for these measurements. The suitability of Gafchromic films and their accuracy in the measurement of relative dose distributions has been confirmed by measurements carried out in the above-mentioned semi-anatomical phantom, by comparisons with Monte Carlo calculations and calculations by the treatment planning system in selected clinical conditions.

The project has provided a method for the verification of dose distributions in gynaecologic and ophthalmic treatments and information on the accuracy and reliability of the methods of measurement, for use in the regulatory control of brachytherapy. The results of the energy response testing have been presented at the IAEA IDOS conference (Jokelainen I et al. 2010). A conference presentation and a scientific paper will be prepared to publish the results of measurements and calculations of brachytherapy sources in clinical conditions.

Development of methods for determination of dose distribution in IMRT treatments (2008–2011)

The aim of the project was to enable accurate and reliable dosimetry in modern therapy techniques for small and shaped radiation fields. More specifically, the aim for STUK was to develop a suitable method (dosimeter and measurement phantom) for the verification of IMRT dose distributions in prostate treatments. STUK was a leader of the work package for the verification of treatment planning systems in IMRT.

The measurement methods selected and tested at the standard dosimetry laboratories were further tested in clinical IMRT beams. In particular, the use of Gafchromic film in the measurements and the developed phantom were tested.

The dose distributions obtained with different methods were compared with each other and with Monte Carlo calculations for selected prostate treatments. The results were also compared with those obtained by the treatment planning systems. Evaluation of the suitability of the methods was based on estimation of the uncertainties and the general feasibility of the measurement techniques, both in laboratory testing and in the measurements in clinical IMRT beams.

The project provided a method for the verification of dose distributions in IMRT treatments and information on the accuracy and reliability of the methods of measurement. These results will also directly be used for the regulatory control of external beam therapy in Finland.

6.3.2 Other use of radiation

Stakeholder involvement in radioactive metal recycling decision-making

The aim of the project was to improve the safety of recyclable radioactively contaminated and activated metals cleared from regulatory control by developing stakeholder involvement methods and improving the transparency of decision making. It focused on the processing of activated and contaminated scrap metal that has been exempted from official regulatory control. The aim was to assess the serviceability of methods used elsewhere supporting stakeholder involvement in scrap metal processing. A further aim was to improve the transparency of policymaking at STUK with respect to the regulatory control of radioactive scrap metal, and to prepare a long-term action plan for regulatory control.

The project was carried out in collaboration with the University of Manchester, School of Science and Engineering and Manchester Business School, and is a part of a PhD degree at Manchester University.

The stakeholder involvement methods for activated and radioactively contaminated metals reuse and recycling were assessed through a literature review and through questionnaires. The identified methods were compared with the stakeholder involvement methods used in other areas of radiation and nuclear safety. The project also included attendance in two courses organised by Manchester University and relevant international seminars.

The results of the project have been presented in a PhD transfer report and also published as articles (Koskelainen 2009a, 2009b, 2011). The results will improve the use of decision support methods and stakeholder involvement at the Radiation Practices Regulation department of STUK. The results are also being used to prepare an action plan for the control of cleared metals from industry, and the main findings will be considered in the revision of the regulatory guide ST 1.5 Exemption of the use of radiation from the safety licence and reporting obligation.

6.4 Occurrence and mitigation of natural radiation

Radon policy in Finland

STUK has carried out surveys of indoor radon, radon mitigation in existing dwellings and prevention in new building. The aim of these studies has been the production of expert information for prevention of the harmful effects of high indoor radon concentrations. The results and the experience have been utilised in the development of guidance work and a national radon strategy in cooperation with authorities.

Dissemination of the results

The first aim of STUKs radon policy is to prevent the harmful effects of radon exposure. The research carried out in 2005–2010 has also had a strong emphasis on the development of radon reduction technologies. The most effective means for the dissemination of the results has been considered to be through publication in national reports (STUK-A series) and in national fora. The policy of STUK has been to maintain the research on indoor radon as a part of the national research on indoor air quality. STUK has regularly presented research results in the main national annual indoor air seminar. Throughout the 2000s, STUK has also had active communication cooperation with Finnish non-governmental organisations and societies in the area of healthy indoor air. Information has also been disseminated in several articles in national newspapers, journals and books.

In order to present the Finnish results to the scientific community, several peer-review proceedings or journal articles have been published. The research carried out still serves as a basis for further peer-reviewed articles.

At the national level, an evaluation of the exposure of Finns to chemicals and radiation was carried out in the mid-2000s (Jantunen et al. 2006). Indoor radon was one of the topics evaluated.

International activities and national radon policy

STUK participated in the WHO International Radon Project during years 2005–2008 and contributed to the WHO Handbook on Indoor Radon, A Public Health Perspective (WHO 2009). This handbook includes new recommendations for national reference levels. The recommendations arise from a new pooled lung cancer risk estimation published in 2004–2005. WHO proposed a reference level of 100 Bq/m^3 to minimise health hazards due to indoor radon exposure. Under prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq/m^3. In 2010, STUK prepared a new proposal on the indoor radon reference level to the Ministry of Health and Social Affairs. The proposal includes a single reference level of 200 Bq/m^3, while the present reference levels are 400 Bq/m^3 for existing dwellings and 200 Bq/m^3 for new buildings. In 2011, the proposal is in preparation in the Ministry.

In the RADPAR project (Radon Remediation and Prevention, EU DG SANCO), STUK has been able to disseminate Finnish knowledge and to learn about the remediation technologies and radon strategies in the other 12 participating countries.

The science base and information needs in the Finnish indoor radon policy was evaluated in 2007 in an ENHIS project (European Environment and Health Information System, WHO) (Kunseler et al. 2007). The information needs assessment was based on documents of Finnish radon policies and on a workshop by radon experts from STUK, the Ministry of Social Affairs and Health, Ministry of Environment and municipal authorities. The assessment covered the science base, policy formulation, implementation and evaluation. In the evaluation of the policy, the radon surveys and studies of mitigation activities and their effectiveness carried out by STUK had an important role. Among many recommendations, the needs for preventive practices to reduce radon concentrations in Finnish houses, increased public awareness and better communication between actors were emphasised.

A summary of the radon policy in Finland, achievements and challenges was presented in an international meeting on Natural Radiation (Arvela et al. 2008a).

Since 2010, STUK has had a representative in Report Committee 27 of the International Commission on Radiation Measurements and Units (ICRU) on Measurements and Reporting of Radon Exposures.

6.4.1 Indoor radon

Occurrence of radon

Radon in Finnish dwellings – sample survey 2006

In the survey carried out in 2006, 2882 randomly selected dwellings were measured using STUK's alpha track detectors (Mäkeläinen et al. 2009, 2011). The first measurement took place from April to November 2006 and the second one from November 2006 to April 2007. The nationwide annual average concentration was 121 Bq/m^3 in houses and 49 Bq/m^3 in flats. The total average of the 2 882 dwellings measured was 96 Bq/m^3. The percentages of dwellings exceeding 200 Bq/m^3 for houses and flats were 15.1% and 1.5%, and 10.4% for all dwellings.

The main aim of the survey was to characterise the changes in building practices that have taken place since the previous nationwide sampling survey in 1990−1991. Radon concentrations are highest in houses built in the 1980s and 1990s. The concentrations in new houses have been decreasing since the 1990s, as radon preventive measures have become common in new construction, especially in radon-prone areas. The recently increased popularity of a crawl space foundation type and the changeover in ventilation strategy to a mechanical supply and exhaust ventilation strategy have also contributed to the decrease in radon levels.

There are also factors that are retarding the downward trend in radon levels. Radon concentrations are higher in the popular semi-basement houses with leaking walls in contact with soil and living spaces in the lowest floor than in older houses with a full basement. In addition, the growing use of permeable light-weight concrete blocks as a building material for foundation and basement walls instead of cast concrete has increased radon concentrations.

Radon risk mapping and Radon Atlas of Finland

STUK is maintaining a national indoor radon measurement database. It is based on measurements in dwellings carried out using STUK's alpha track radon detectors. Most of the measurements are ordered by private persons or municipalities, but measurements carried out in various research projects are also included. The database includes information on building characteristics (foundation type, ventilation strategy, radon prevention etc.) from a 2-page questionnaire filled in by the resident. Radon maps are provided on STUK's Internet pages.

The Radon Atlas of Finland 2010 (Valmari et al. 2010b, 2011a, 2011b) summarises the latest radon measurement situation in Finland. It contains measurement data from 87 000 dwellings in houses and 5 000 flats. About 6% of all dwellings in houses and 0.4% of flats in Finland have been measured. The regional and municipal statistics presented in the Atlas indicate that measurements are more common in radon prone areas. Regionally representative estimates of radon parameters were determined by calculating their values in 1-km grid squares, and by weighting each square by the number of dwellings in it. The estimated mean annual average radon concentration in Finnish houses is 142 Bq/m^3, and the proportions of houses exceeding 200 Bq/m^3 and 400 Bq/m^3 are 17% and 5%, respectively. Similar estimates are presented also for each of the 20 regions and also for 247 out of the 342 municipalities in Finland. There were not enough measurements in the remaining 95 municipalities for a reliable estimate. Radon concentrations are highest in a uniform area comprising six out of the 20 regions in Finland: Itä-Uusimaa, Päijät-Häme, Kymenlaakso, Kanta-Häme, Pirkanmaa and South Karelia. The mean radon concentration in low-rise residential buildings is shown in national and regional maps.

The recent decreasing trend in radon levels is demonstrated by separate maps of mean concentration in houses built in the 1970s, 1980s, 1990s and 2000s. The maps also demonstrate the effects of soil type and foundation type on indoor radon. Separate national maps are presented for those blocks of flats with soil or rock directly underneath, and for other flats. These demonstrate that high radon levels are also a common problem in the lowest-floor flats of buildings that have no cellar or other kind of room under them.

The location of radon-prone areas has traditionally been the main application of database material. However, the cumulative number of measurements is already so large that additional data no longer significantly increases our knowledge of the spatial distribution of radon-prone areas in Finland. For wider utilisation of the large database material, we are developing methods to compensate for the unrepresentative nature of the material. Due to the large number of measurements in radon-prone areas, the geographical distribution is uneven. This can be compensated for by weighting the data with the local housing density (Valmari et al. 2010a, 2011b). The database material provides a cost-effective means for updating national and regional radon statistics. The national radon trend (average radon concentration vs. construction year) calculated from the database material using housing-density compensation has a good agreement with the representative curves obtained in the national sampling surveys. The most significant distortion in the database material concerning house-specific factors is the overrepresentation of houses with radon preventive measures implemented, especially outside the radon prone area (Valmari et al. 2011b). This needs to be taken into account for a more accurate follow-up of the current radon trend in Finland. The large cumulative data utilised together with the representative survey data also provides a potential tool for analysing effects of various building practices on indoor radon (Valmari et al. 2011b).

By the summer of 2010, radon measurements had been carried out in 94 000 dwellings in low-rise residential buildings and 5 200 flats. Radon levels exceeding 200 Bq/m^3 were found in 35 000 dwellings in low-rise residential buildings and 1 100 flats. Radon levels exceeding 400 Bq/m^3 were found in 15 000 dwellings in low-rise residential buildings and 600 flats.

Modelling factors affecting indoor radon

The effects of various geological, meteorological and house-specific factors on the measured indoor radon concentration were studied in co-operation with the University of Jyväskylä, Department of Mathematics and Statistics (Kinnunen 2008). A mixed linear model was introduced to consider the stronger correlation in indoor radon between the houses located close to each other as compared to those far apart. The model was applied to 908 houses located in the regions of Kanta-Häme and Päijät-Häme measured with STUKs alpha-track detectors. The main factors affecting indoor radon were soil type, uranium content in soil, outdoor temperature, ventilation strategy, foundation type, building material, installation of radon piping and number of floors in a house. A linear model obviously cannot accurately describe the complicated interactions of the various parameters and indoor radon. However, the modelling results do increase our understanding of the phenomena.

STUK has studied the seasonal variation in radon concentrations (Arvela 2005a). The model calculations supported by the observations show that the cold Scandinavian climate increases indoor radon concentrations by 50% in comparison with the South of Europe. The ratio of the winter concentration to the annual average is typically 0.7–0.9 in the European countries, independently of the climatic conditions.

Radon in Finnish workplaces

In Finland the action level for the radon concentration in air is 400 Bq/m^3 in workplaces where people are working regularly (1 600 hours per year). This radon concentration represents the annual mean of the radon concentration during the working time. The mean radon concentration may be higher than 400 Bq/m^3 if the work is not regular. The action levels for the radon concentration should also be applied to public buildings, such as schools and underground rooms intended for the public.

During the seasons 2005–2007, 408 employers ordered and sent back 1 630 radon measurements. Passive alpha track detectors of STUK were used for these mainly two-month measurements. The average recorded radon concentration was 290 Bq/m^3 and the median 94 Bq/m^3. In 260 workplaces the radon concentration was more than 400 Bq/m^3, and in 94 places it was more than 1 000 Bq/m^3, the highest value being 13 300 Bq/m^3 (Reisbacka 2008).

Case studies of radon mitigation in seven large school and industrial buildings were published in 2005 (Reisbacka 2005). Typical reduction factors in the radon concentration were 80–90% and the best result was above 95%.

A national day care centre radon survey was carried out during February–May 2006 (Valmari et al. 2007). The campaign was focused in new buildings. Local health-care authorities selected 1–3 of the newest day care buildings from each municipality. A total of 367 day care centres were measured. The average concentration was the highest in the buildings constructed during the 1990s, being 59 Bq/m^3. The centres constructed since 2000 had a radon average of 50 Bq/m^3.

Radon exposure and dosimetry

The total exposure to inhaled radon received indoors at home and at work, as well as outdoors was estimated in a random sample questionnaire study in which the proportion of time spent at home, at work, outdoors and in other locations and indoor radon concentrations were analysed (Mäkeläinen et al. 2005). The mean proportion of the time Finns spend at home was 0.73, and in private dwelling environments in total, 0.77. The proportion of time spent at work, at school, and in public buildings was 0.14, and that spent outdoors and in vehicles 0.09. The average radon concentration in dwellings was 104 Bq/m^3, in workplaces 30 Bq/m^3, and that recorded by personal dosimeters was 85 Bq/m^3. The concentration calculated from individual occupancy factors and their respective radon concentrations was 88 Bq/m^3. This study showed that the occupancy weighted radon exposure was 15–18% lower than the radon exposure at home.

The dose conversion factor from the radon gas concentration to the effective radiation dose is affected by the indoor air aerosol particle concentration, as the dose from a radon progeny attached to an aerosol particle is smaller than that from an unattached one. Measurements of radon progeny and aerosol particle-size distribution in a normally occupied residential building, carried out together with the University of Helsinki, Department of Physical Sciences, were reported in Valmari et al. (2005). The results suggest that most of the dose in a modern Finnish house with a low indoor air aerosol particle concentration could be caused by the unattached radon progeny. Determination of the aerosol particle-size distribution, instead of just their total concentration, was found to be essential for more precise quantification of the behaviour of radon progeny.

Radon prevention and mitigation

Radon prevention in new construction – Sample survey 2009

According to the Finnish guidelines, new buildings should be designed and constructed so that the indoor radon concentration is below 200 Bq/m^3. In wide areas of Southern Finland this limit is exceeded in 20–50% of houses. Indoor radon concentrations in the new construction are the key factor affecting long-term radon exposure. The regulatory and research work has pursued effective measures and practices for the reduction of radon concentrations in new construction. STUK has actively participated in the development of the national radon prevention guidance. The research and guidance for radon prevention in new construction have been presented in several national and international meetings and journal articles (Arvela 2005b, Arvela et al. 2005, Keränen and Arvela 2008, Arvela 2010a, 2010b, 2010c).

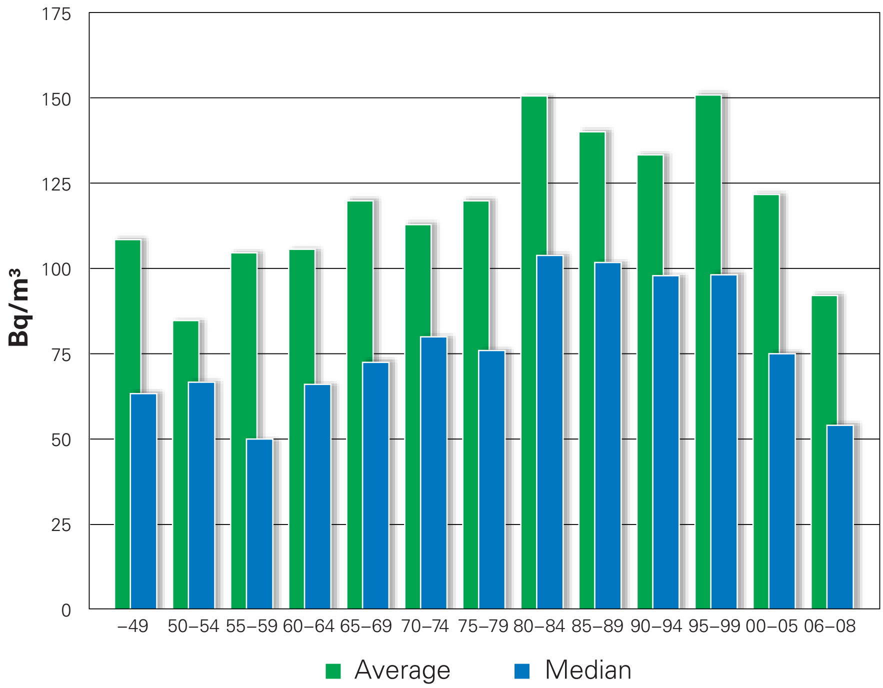

Figure 18. Radon concentration in low-rise residential houses according to the year of construction based on the national sample survey in 2006 (1949–2005). The last bar (2006–2008) represents the results of the new construction sample survey in 2009.

In 2009, STUK launched a new survey in order to explore the status of radon prevention work. The building code for radon prevention and the associated practical guidelines were revised in Finland in 2003–2004. Thereafter, preventive measures have become more common and effective leading to a marked reduction in indoor radon concentrations. In the new construction survey in 2009, the indoor radon concentration was measured in 1 561 new low-rise residential houses (Arvela et al. 2010, 2011). The houses were randomly selected and represented 7% of the houses that received building permission in 2006. The average radon concentration of all measured houses, which were completed in 2006–2008, was 95 Bq/m^3, the median being 58 Bq/m^3. The average was 33% lower than in houses completed in 2000–2005 (Fig. 18). The decrease was 47% in provinces with the highest indoor radon concentration and 26% elsewhere in the country. In houses with a slab-on-ground foundation that had both passive radon piping and sealing measures carried out using a strip of bitumen felt in the joint between the foundation wall and floor slab, the radon concentration was on average reduced by 57% compared to houses with no preventive measures. Preventive measures were taken nationwide in 54% of detached houses and in provinces with the highest radon concentration in 92% of houses. The effectiveness of radon prevention in the radon-prone provinces is extremely high and the results indicate that radon preventive measures should be required in the building permission process in all parts of the country. Widespread and skilled implementation of preventive measures throughout the country could result in an average 50% reduction in indoor radon concentrations compared to the present housing stock with no preventive measures. This would considerably reduce exposure to radon and the harmful health effects of indoor radon in the coming decades.

Radon mitigation in existing dwellings

We estimate that altogether 59 000 dwellings (51 000 low rise residential buildings, 8 000 flats) in Finland exceed the action level for remedial measures. Approximately 4 500 of these have been remediated. Reduction of both the average exposure to indoor radon and the highest radon concentration in dwellings is the main target of radon remediation work. One of the objectives of STUK's radon policy has been to provide science-based practical guides for radon remediation. STUK has prepared such guidance in cooperation with the Ministry of Social Affairs and Health, Ministry of Environment and Helsinki University of Technology. In 2005–2010 the emphasis was on the development of the STUK radon mitigation guide.

The new guide published in 2008 (Arvela and Reisbacka) utilises the results of an extensive radon mitigation questionnaire study carried out in 2000–2002 and other previous studies of STUK and the Ministry of Environment. The guide provides basic information about all mitigation methods used in Finland. The most efficient methods are sub-slab depressurisation (SSD) and a radon well. Typical radon concentration reduction factors are 70–90% for both methods. The guide gives detailed information with many examples for SSD and radon well design and implementation. Sealing entry routes normally resulted in reduction factors of 10–40%. Complete sealing may be demanding and expensive. Improved ventilation resulted in only a few cases in a reduction factor higher than 50%. The installation of fresh air vents in some cases reduces the depressure level of the house and the inflow of radon bearing soil air. Installation of SSD, a radon well or fresh air vents are the most effective measures in blocks of flats. The guide also briefly handles radon mitigation in workplaces and large buildings. The guide has additionally been published in Swedish (Arvela and Reisbacka 2009) and is available free of charge via the STUK Internet site.

Results on radon mitigation in blocks of flats have been reported in a national seminar and international meetings. Results of the studies on radon remediation have been presented in several national and international meetings and journal articles (Arvela 2011, Arvela and Reisbacka 2008b, 2011).

Radon Prevention and Remediation – RADPAR

STUK has been participating together with 13 other EU countries the RADPAR project (Radon Prevention and Remediation, 2009–2012). The main objectives of RADPAR are:

- The development of policies and strategies to promote effective radon prevention and remediation
- The establishment of an EU radon risk communication network
- The assessment and harmonisation of radon control technologies in Member States
- Analysis of the cost-effectiveness and health benefits of radon control strategies

The key role of STUK has been to carry out a questionnaire study on the results and techniques used in radon remediation in existing dwellings and prevention in new construction (WP 6.1.1). The draft results were presented to the participants in 2010 (Holmgren and Arvela 2010). The final report will be published in 2011. STUK has also participated in research on the effects of modern energy saving passive construction technologies on indoor radon concentrations. Preliminary results were communicated in a Refresher course of the IRPA 2010 meeting (Arvela 2011). STUK will publish the key results of WP 6.1.1 as a STUK-A-series report: Assessment of current techniques used for reduction of indoor radon concentration in existing and new houses. A refereed journal article is also in preparation. The key findings of the study are:

- The number of houses with an elevated indoor radon concentration in EU countries typically ranges from tens of thousands to two million. The percentage of these houses already remediated varies from zero to 15%.
- Preventive measures been taken in new construction ranging from a small number of houses to over half a million houses. The research data on the current situation, the number of houses with preventive measures and the efficiency of these measures is currently still quite inadequate.
- The most efficient remediation method is active sub-slab depressurisation (SSD) and a radon well, the reduction of radon concentration being 60–95%. Other methods, such as sealing entry routes and improving ventilation in living spaces, in cellar or in crawl space, are less effective, the reduction of radon concentration typically being 10–60%.

- Active SSD is also the most efficient prevention technique. The efficiency of passive SSD and passive radon piping is lower, typically 20–50%. However, wide use of passive radon piping can be recommended. Radon-proof insulation with a membrane and sealing of pipe penetrations reduces the radon concentration by an average of 50%.
- The impact of remedial techniques and preventive techniques on energy consumption is highest for active SSD, mainly due to the power consumption of the electrical fan. Replacing an existing natural or mechanical exhaust ventilation with a new mechanical supply and exhaust ventilation with a heat recovery system can reduce energy consumption
- Sealing the constructions of house foundations in contact with soil and control of air flows in standard, low energy and passive construction have synergistic goals. The reduction of soil-air flows into the house reduces indoor radon concentrations and simultaneously also the energy consumption.

Radon campaigns

Radon campaigns aim at activating citizens to carry out indoor radon measurements and remediation as well as increasing the common awareness of indoor radon questions. Through radon campaigns, STUK also promotes the attainment of those goals that the Ministry of Social Affairs and Health has set for municipal authorities in Finland for prevention of the harmful effects of radon. The Ministry of Social Affairs and Health supports this campaign. Radon campaigns were started in autumn 2003. By autumn 2010 the campaigns had already been organised in 72 regions in a total of 175 municipalities. In some municipalities two campaigns have been arranged. Altogether, 27 000 houses have been measured and in 4 600 of these the action limit for radon remediation of 400 Bq/m^3 has been exceeded. The radon concentrations measured in the campaign regions have exceeded the action limit of 400 Bq/m^3 in 0–39% of houses (average 15%), depending on the region. The remediation activities have been followed by sending a special questionnaire on remediation performed to the house owners. In 2006–2007, a questionnaire was sent to those households where the radon concentration of 400 Bq/m^3 was exceeded during the two first campaign seasons. Among the households that responded the questionnaire, 37–60% had taken remedial measures. The results of radon campaigns were published as a research report in 2008 (Arvela et al. 2008b) and presented at a national meeting. Local health authorities have regularly received updated results from the campaigns.

The results confirm that the present authority orders and regulations given on radon prevention in new buildings should be followed in the whole country. Radon mitigation training for construction companies is one part of the campaign programme. Since 2003, nine one-day training courses have been organised with a total of 360 participants from companies and municipalities. Training courses have also promoted the supply of radon mitigation services.

6.4.2 Uranium and radon in the geosphere and in drinking water

Uranium and radon in the geosphere

In co-operation with Eötvös University in Hungary, the University Helsinki and Geological Survey of Finland, STUK has carried a multidisciplinary analysis of Finnish esker sediment in radon source identification and of radon emanation in mineral grains (Breitner et al. 2008, 2010). These results formed part of the doctoral thesis of Daniel Breitner in Eötvös University, Budapest (Breitner 2011). The analysis provided new mineralogical results on uranium and radium in Finnish esker sediments.

Monazite and xenotime were the most important uranium-bearing minerals and potential radon sources and affected the distribution of uranium and thereby radium in separate grain-size fractions. The esker sand has been exposed to no significant weathering, and radium has not therefore been separated much from uranium. The smallest grain-size fraction of the esker sand had a higher radon emanation power (0.24) than the other fractions (around 0.17). In soils and sediments, moisture adsorbed on particle surfaces and in the pore system significantly affects the behaviour of recoiling radon atoms after the decay of parent ^{226}Ra, leading to increased radon emanation. Six different grain size fractions were studied from an esker sand sample at 0%, 5% and 10% moisture contents relative to the mass of solids (Breitner et al. 2010). In a further study, necessary complementary information on the chemical and structural distribution of ^{226}Ra was gained by selective leaching experiments. The results revealed an increase in the ^{226}Ra concentration from 50 Bq/kg in grain sizes of 1–2 mm to 200 Bq/kg in the grain-size fraction <0.063 mm. Respectively, the emanation factor increased from 0.12 to 0.30 at a 5% moisture content. Both the emanation factor and radium concentration increased significantly when the grain size was below 0.125–0.250 mm. Above this fraction, the emanation fraction was approximately constant, 0.13 at a 5% moisture content. In most of the grain-size fractions, emanation reached its maximum at a 5% moisture content, being twice as high as in a dry sample. For the small particles (<0.063 mm), the ^{226}Ra distribution was rather complex and dependent on the mineral composition compared to larger particles, wherein emanation from the internal pore system and the adjacent matrix dominated over the contribution from the external surface.

In addition, expert services have been provided for the STUK group of Nuclear Waste and Material Regulation and there has also been co-operation with the University of Helsinki in studies on uranium mineralisation, diffusion and the residence time of solutes in rock matrix, supporting the evaluation of nuclear waste repositories. (Hellmuth 2007, Sardini et al. 2007, Read et al. 2008, Robinet et al. 2008).

Intake of natural radionuclides from drinking water

Natural radionuclides in Finnish ground waters (both wells and public water supplies) have been surveyed since the late 1960s, and the first representative sample survey of public water supplies was published in 1978. Subsequently, water sample measurements have mostly been carried out in drilled wells located in the risk areas where high concentrations of radon, uranium or other natural radionuclides had been found. Currently, activity concentrations of natural radionuclides have been determined in more than 11 000 ground water samples (Salonen 2006a). In order to investigate the representative mean activity concentrations of natural radioactivity in well waters, a new population-based random study of 472 private wells was initiated. The mean concentrations of ^{222}Rn, ^{226}Ra, ^{234}U, ^{238}U, ^{210}Pb and ^{210}Po in drilled wells were 460, 0.05, 0.35, 0.26, 0.04 and 0.05 Bq/l, and in wells dug in soil 50, 0.016, 0.02, 0.015, 0.013 and 0.007 Bq/l, respectively. Approximately 10% of drilled wells exceeded a radon concentration of 1 000 Bq/l and 18% a uranium concentration of 15 μg/l. The mean annual effective dose from natural radionuclides for a drilled well-user was 0.4 mSv and 0.05 mSv for a user of a well dug in soil. The effective dose arising from ^{222}Rn was 75% from the total of all natural radionuclides for drilled well-users. Regarding long-lived radionuclides, ^{210}Po and ^{210}Pb caused the largest portion of the effective dose. The dose arising from ^{238}U and ^{234}U and ^{226}Ra was only 8% of the total of all natural radionuclides (Vesterbacka et al. 2005b, Vesterbacka 2007).

The activity concentrations of ^{226}Ra and ^{228}Ra were examined in more detail in 176 water samples from drilled wells. ^{226}Ra activity concentrations were in the range of <0.01 to 1.0 Bq/l and ^{228}Ra activity concentrations in the range of <0.03 to 0.3 Bq/l. The mean activity concentrations of ^{226}Ra and ^{228}Ra were 0.041 and 0.034 Bq/l, respectively. High radium activity concentrations in drinking water were rare. Only 2–4% of the drilled wells exceeded a ^{226}Ra concentration of 0.5 Bq/l and 1–2% of the wells exceeded a ^{228}Ra concentration of 0.2 Bq/l (these activity concentrations cause an annual effective dose of 0.1 mSv). The maximum annual effective doses from ^{226}Ra and ^{228}Ra for users of drilled wells were 0.21 mSv and 0.16 mSv, respectively. The elevated activity concentrations of ^{226}Ra and ^{228}Ra did not occur simultaneously in the same ground waters and the correlation between ^{226}Ra and ^{228}Ra was weak (Vesterbacka et al. 2006).

Removal of radionuclides from household water

In Finland, private wells are used as drinking water sources in about 500 000 permanent residences and about 200 000 holiday houses. Presently, about 40% of the wells in permanent use are wells drilled in bedrock. Especially in granite rock areas, drilled wells may contain too high concentrations of radionuclides, whereas the activity levels in dug wells are typically much lower.

Domestic radon removal units based on aeration have been commercially available since the late 1990s. In order to determine how effectively these units remove radon, a new test protocol was developed applying frequent sampling while letting 100 litres of water flow. In this way, removal efficiencies could be more accurately calculated and possible malfunctions detected. Seven models of domestic aerators designed for removing radon from household water were tested. The average removal efficiencies for 100 litres with a medium flow rate were 86–100%. By conducting a questionnaire study, typical problems related to the aeration units were localised and recommendations on maintenance and installation were given accordingly (Turtiainen 2009b).

In drilled well water, the removal of ^{210}Po and ^{210}Pb is difficult, since they are often bound to particles of different sizes. Therefore, the distribution of ^{210}Pb and ^{210}Po in particles of various sizes in untreated Finnish groundwater was investigated, as well as the effect of water treatment on this distribution. Information was needed to attain better removal efficiencies using water treatment equipment. Sampling was carried out at five private homes. Each site had water treatment equipment, either an ion exchange unit or a granular activated carbon filter. The water samples from both raw and treated water were filtered using a pore size ranging from 450 nm to 100 kDa, and the activity concentration of ^{210}Po and ^{210}Pb in the filtrate was determined. In untreated groundwater, 86% of ^{210}Pb on average was found in the large particle fraction (>450 nm), except in Fe- and Mn-rich water with a high Fe/Mn ratio and organic-rich water. In those waters, the main part of ^{210}Pb was found either in the intermediate particle (100 kDa – 450 nm) or in the small particle (<100 kDa) fractions. Compared to ^{210}Pb, more ^{210}Po was bound in the intermediate and small particle fraction. After water treatment, ^{210}Pb was found in most cases in the large particle fraction. The size distribution of particle-bound ^{210}Po was not as clear as it was for ^{210}Pb, and in treated water ^{210}Po was found more evenly in fractions. The ion exchange unit removed ^{210}Pb and ^{210}Po bound in the intermediate particle fraction or in the small particle fraction, whereas the removal efficiency of the activated carbon filters concerning ^{210}Pb and ^{210}Po was independent of the particle size (Vesterbacka et al. 2005a).

Removal of radionuclides in conjunction with Fe or Mn is often needed. Considerable economic savings would be made if all these elements were removed simultaneously using only one removal unit. Therefore, a study on the usability of Fe and Mn removal equipment to remove natural radionuclides was initiated. The study established which techniques have potential for further studies and whether any technical changes could be made to improve the removal efficiencies. The ability of conventional Fe/Mn removal equipment to remove ^{222}Rn, ^{226}Ra, ^{238}U, ^{210}Pb and ^{210}Po from private well water was examined at 12 houses in Finland. The operational principles of the equipment were based on aeration and filtration, ion exchange or manganese greensand filtration. The results indicated that ^{222}Rn removal efficiencies using aeration and filtration varied greatly, from 10 to 90%. The best removal efficiencies for ^{238}U and ^{226}Ra, i.e. from 80 to 99%, were attained by ion exchangers when anion and cation resins were used in the same filter. Manganese greensand filtration removed over 95% of ^{226}Ra but less than 60% of ^{238}U. Highly variable efficiencies of the equipment in removing ^{210}Pb and ^{210}Po, raning from 0 to 97%, were observed. However, in most of the test sites studied, the activity concentrations of various radionuclides in the treated water were below the guideline values set in Finland (Vesterbacka and Salonen 2008a, Vesterbacka and Salonen 2008b).

Since household water treatment units intended for the removal of radionuclides have been on the market since the 1990s, an analysis of their effect on the collective effective dose was carried out. The analysis also considered the development of legislation, regulations and political decisions made so far that have affected the amount of public exposure to radon from drinking water. A review of the studies on radon removal techniques was provided, together with newly obtained results. New data on the transfer of radon from water into indoor air were presented. The new assessments took into account the expanding use of domestic radionuclide removal units by Finnish households (Turtiainen and Salonen 2010). A doctoral dissertation on the mitigation of radiation exposure to radon by household water treatment is being prepared.

6.5 Environmental research

6.5.1 Aquatic environment

Freshwater radioecology

Fish is one of the natural products that still contain elevated ^{137}Cs concentrations originating from the Chernobyl accident and thus contributes to the internal dose of Finns. Therefore, several research projects have been carried out to address the environmental factors affecting the behaviour of ^{137}Cs in the freshwater environment. Saxen et al. (2010) demonstrated the different behaviour of ^{137}Cs in seepage and drainage lakes that had not been reported earlier. Research has also been carried out to study the accumulation of ^{137}Cs in fish (Saxén et al. 2009, Saxén 2007b), to investigate the processes leading to the long retention time of ^{137}Cs in fish and water (Saxén and Ilus 2008) and to further understand the behaviour of ^{137}Cs in the freshwater environment (Saxén and Koskelainen 2005, Saxén 2006, Saxén in STUK-A217 (Ikäheimonen 2006), Ilus and Saxén 2005, Saxén and Sundell 2006, Saxén 2007c). To summarise all the research that has been carried out in freshwater radioecology at STUK since the 1960s, Saxen and Outola (2009) compiled a summary report that also contained a chapter how to estimate the concentration of ^{137}Cs and ^{90}Sr in an emergency situation.

In addition to ^{137}Cs, another long living radionuclide, ^{90}Sr, has also been the subject of research (Saxén 2005, Saxén 2007a, Outola et al. 2009a). The water chemistry of lakes, particularly the calcium concentration and electrical conductivity, was shown to strongly influence the accumulation of ^{90}Sr in fish (Outola et al. 2009b). As the ^{90}Sr accumulation in fish is lower in waters with high Ca concentration, liming of lakes could be considered as a possible countermeasure in case of a radioactive accident. This was tested in a field experiment where a small acidified lake was divided into two parts, one half was limed with calcium carbonate and the other half was left unlimed for control purpose. Results showed that even though ^{90}Sr uptake in fish decreased as expected due to the increased amount of Ca in the water, the ^{90}Sr concentration in fish remained unchanged. This was due to the increased ^{90}Sr concentration in the water, as ^{90}Sr was released from the sediment when the Ca concentration in the water increased. The results did not support the use of liming as a countermeasure in lakes contaminated with ^{90}Sr, especially if not carried out in a fresh fallout situation.

Marine radioecology

Of all the seas in the world, the Baltic Sea is the most contaminated with ^{137}Cs and it has therefore been the focus of several research projects. Radioecological research in the Baltic Sea has mainly been carried out in co-operation with the Helcom-Mors project group (the Helsinki Commission – Monitoring of Radioactive Substances). Long-lived radionuclides in the seabed of the Baltic Sea were evaluated by Ilus et al. (2007), and the Laboratory was responsible for writing several chapters in the fourth joint report “Radioactivity in the Baltic Sea in 1999–2006” related to sources of radioactivity, radionuclides in seawater and sediments and data quality (Herrmann et al. 2009, Ikäheimonen et al. 2009b, Lüning et al. 2009, Mattila and Ilus 2009).

A summary of the impact of the Chernobyl accident on the Baltic Sea was completed by Ilus et al. (2008), and Ikäheimonen et al. (2009b) assessed the inventories and temporal trends in ^{137}Cs and ^{90}Sr in Baltic Sea water and sediment since the 1960s. The effective half-lives of ^{137}Cs and ^{90}Sr are long in seawater: 10 and 16 years, respectively. Over time, sediments are becoming an important depository for these radionuclides in the Baltic Sea, but not necessarily the final depository, as the radionuclides may be released from the sediments under different environmental conditions or through human activity. Other research activities in Baltic Sea during the reporting period included studies on sediments (Mattila et al. 2006a, Mattila et al. 2006b) and on indicator organisms and wildlife (Ilus et al. 2005, Ilus et al. 2006, Ilus 2006).

Studies on the behaviour of radionuclides in the environs of nuclear power plants and the environmental effects of Finnish nuclear power plants

A thorough investigation of the environmental effects of thermal and radioactive discharges from nuclear power plants conducted by Ilus (2009) covered the entire life span of nuclear power in Finland. This academic dissertation was a compilation and a summary of results yielded in monitoring programmes and environmental studies carried out during more than 40 years in the sea areas surrounding the Finnish nuclear power stations. The results indicated that the radiation doses to the public caused by discharges of radioactive substance from the Finnish nuclear power plants were very small. The effects of the thermal discharges were more significant, at least to the wildlife in the discharge areas of the cooling water. The results also revealed that the nutrient level and the exchange of water in the discharge area are of crucial importance. In addition to the above-mentioned academic dissertation, there are ongoing studies on the behaviour of radionuclides in the vicinities of nuclear power plants in Finland that are periodically published (Ilus et al. 2008).

6.5.2 Terrestrial environment

Forests

Guidance for sampling in forests, Forest seminar and Forest network under the project NKS-FOREST

The project FOREST was carried out under Nordic Nuclear Safety Research within the framework of the NKS-B programme, and involved four Nordic organisations. The project was established to prepare a guide for sampling in forest ecosystems for radionuclide analysis (Aro et al. 2009). The aim of the guide was to improve the reliability of datasets generated in future studies by promoting the use of consistent, recommended practices, thorough documentation of field sampling regimes and robust preparation of samples from the forest ecosystem. The guide covers the general aims of sampling, the description of major compartments of the forest ecosystem and outlines key factors to consider when planning sampling campaigns for radioecological field studies in forests. Recommended and known sampling methods for various sample types were also compiled and presented. The guide focuses on sampling practices that are applicable in various types of boreal forests, robust descriptions of sampling sites, and documentation of the origin and details of individual samples. The second part of the project was a seminar entitled “Towards improved understanding of radionuclide transfer in forests and preparedness to handle contaminated forests”, which was held at STUK in 2008 (Vetikko et al. 2009). The seminar provided a forum for the exchange of information by Nordic scientists currently working in the field of forest radioecology or using the data. Presentations of research on nutrient cycling and radionuclide distribution in boreal forests, discussion on the needs for future research and attendance of experts on forestry, forest research and radioecology offered a unique opportunity to disseminate and receive information. The seminar programme was composed of the topics of radioecology and forest research, assessment of radionuclide contamination and management of contaminated forests. Sampling in forests, monitoring and modelling the environmental impact of the disposal of spent nuclear fuel, and recent radioecological studies on forests were also discussed. In the seminar, an informal forest network was launched to support communication and future collaboration among the Nordic scientists involved in research on forests contaminated by radionuclides and for experts on forestry sharing an interest in the radioactive contamination of forests. The network can be accessed at *www.forestnetwork@stuk.fi*.

The effect of wood ash application on ^{137}Cs activity concentrations in Scots pine (*Pinus sylvestris* L.) needles and certain berries and mushrooms was studied on drained peatlands in Northern Finland. The increasing use of wood fuels for energy production in Finland since the 1990s implies that large quantities of the generated ashes will be available for forest fertilisation. The deficiency of information on the effects of wood ash application on ^{137}Cs in peatland forests motivated the study. The results suggested that fertilisation by using ^{137}Cs-containing wood ash reduced the ^{137}Cs activity concentration in the plants of the ecosystem on drained peatlands (Vetikko et al. 2010). The significant reduction in activity in current year needles was associated with the largest dose of nutrients in ash, despite the added ^{137}Cs activity also being highest at that time. The study also provided evidence for the low probability of increasing ^{137}Cs contamination in wild berries and mushrooms. The results are of importance when the recycling of ash is being planned.

The long-term effects of fallout ^{137}Cs on trees have been studied in commercial forest stands situated in Central Finland. Sampling of soil, trunk wood and other parts of trees, and ^{137}Cs determinations of the samples have been carried out for six forest sites thus far.

Foodstuff studies

The focuses in foodstuff studies have been natural radionuclides in the main foodstuffs and ^{137}Cs in wild foodstuffs (mushrooms, berries and game). Studies on natural radionuclides in food have earlier been targeted at reindeer and fish. Natural radioactivity in other food groups has been much less investigated and the dose assessments have largely been based upon values reported by UNSCEAR (2000). Recent aspirations towards commissioning uranium mines in Finland have raised a question about the baseline concentrations of natural radioactivity in various foodstuffs produced in Finland.

In a study on the levels of natural radionuclides in cereal grains, the mean concentrations of ^{210}Pb were found to be, depending on the cereal, 2–7 times higher than the reference values provided by UNSCEAR (Turtiainen et al. 2011). The dose due to natural radionuclides in cereals proved to be about threefold compared to that calculated by using the concentrations of UNSCEAR. This may be attributable to the generally higher natural radionuclide concentrations of Finnish agricultural soils. Artificial radionuclides ^{137}Cs and ^{90}Sr in cereals have been monitored since the 1960s. A slow decline in the levels of ^{137}Cs and ^{90}Sr since the 1990s has continued, the mean levels of the nuclides now being well below 1 Bq/kg. The radiation dose due to artificial radionuclides was 1.5% of the total dose from cereals. A study on the contents of natural radionuclides as well as ^{137}Cs and ^{90}Sr in vegetables is going on to acquire detailed information on the contribution of this food group to the ingestion dose.

The average radiation dose from ^{137}Cs via ingestion in Finland varies regionally from 0.01 to 0.09 mSv/y. The contribution of natural products (wild berries and mushrooms, game, reindeer, fish) is 77–97% of the total dose, although natural products in the diet only account for 5% of the total consumption (Kostiainen et al. 2010). From forest products the dose from wild berries for an average consumer is the highest, but those consuming a lot of natural products (hunters) receive their maximum dose from moose meat (Kostiainen 2007). The ^{137}Cs concentrations in many edible mushrooms still exceed the level of 600 Bq kg^{-1}, especially in those areas where the deposition was highest after the Chernobyl accident (Kostiainen in STUK-A217 (Ikäheimonen 2006), Kostiainen and Ylipieti 2010). Methods to reduce the ^{137}Cs contents of mushrooms by rinsing, soaking and boiling were tested and found to reduce ^{137}Cs by up to 90% (Kostiainen 2005b).

In 2010 the Nordic NKS project Radpast was started, in which radionuclide transfer in the food chain soil–pasture–cow's milk is being studied in all Nordic countries. Sampling is covering clay, sandy and humus soils. The focus is on natural radionuclides, but ^{137}Cs and ^{90}Sr are also being determined.

Built environment

STUK participated in a joint research project studying the environmental impact during the life cycle of Finnish natural stone production. Radiological considerations included surveying the radioactivity of natural stones produced in Finland and assessing the dose from natural radionuclides received by workers at a typical quarry. Doses originating from natural stones used as surfacing materials in buildings were also assessed. According to the results, the excess effective dose to the workers does not exceed 1 mSv/y at the quarries and in buildings, and all the natural stones studied could be safely used as surfacing materials (Turtiainen and Weltner 2007).

A visiting scientist from South Valley University (Qena, Egypt) worked at STUK in 2007–2009 with financial aid provided by Centre for International Mobility CIMO. Natural radioactivity in Egyptian building materials had been reported by several authors in selected cities between 1993 and 2007. This data had not been pooled and analysed further in order to assess the effective doses received by the population. A joint investigation was therefore carried out in order to firstly compile and complement the existing published data and secondly to employ new computational methods in assessing the doses. The effective doses received by the residents of different types of houses within all Egyptian governorates were assessed using the WinMat computer programme. The results were below 1 mSv/y in all cases, and the mean excess effective dose due to building materials was assessed as 0.07 mSv/y (Turtiainen et al. 2008).

6.5.3 Radiation protection for non-human biota

Four projects relating to radiation protection of biota were carried out during the period of this evaluation. The project ERICA (Environmental Risks from Ionizing Contaminants: Assessment and Management, EU, 6th framework programme) was carried out in 2004–2007. The project was coordinated by Swedish Radiation Protection Authority and involved 15 contractor organisations from seven countries. The objective was to provide and apply an integrated approach to scientific, managerial and societal issues concerned with the environmental effects of ionising contamination, with emphasis on biota and ecosystems. The final outcome of the project was the ERICA integrated approach to the assessment and management of environmental risks, and the ERICA Tool, which is a software programme with supporting databases. The Laboratory participated in the development of the assessment methodology by providing default concentration ratios for aquatic biota for the ERICA Tool (Hosseini et al. 2008). STUK also contributed to the development of managerial guidance, which involved stakeholder engagement (Zinger et al. 2007a), and organised one end-user group meeting in Finland (Zinger et al. 2007b). Subsequently, the ERICA Tool was applied to freshwater biota in selected lakes affected by the Chernobyl accident to obtain dose rates from ^{137}Cs, ^{134}Cs and ^{90}Sr (Vetikko and Saxén 2010). The dose rates to most species studied were clearly below the screening level of 10 μGy/h, indicating no significant impact of the Chernobyl fallout on these species.

Transfer factors are widely used in the radiation protection of biota to describe the transfer of radionuclides through food-chains, but for many organism and radionuclides the available data are limited . Some of these data deficiencies were addressed in a Nordic project (GAPRAD) in which the ^{210}Po and ^{210}Pb contents of fish, amphibians, birds and mammals were determined in freshwater, brackish water and terrestrial environments (Saxen et al. 2009, Brown et al. 2009). In EMRAS I, the Laboratory contributed to an intercomparison of models to estimate radionuclide activity concentrations in biota (Beresford et al. 2008) and in EMRAS II the Laboratory took part in the compilation of a handbook on wildlife transfer factors.

6.5.4 Arctic and subarctic environments

The arctic food chain: lichen – reindeer – man

During 2005–2010, the Regional Laboratory in Northern Finland carried out several studies related to the lichen–reindeer–man food chain in which both anthropogenic $^{134,137}Cs$ and $^{210}Po/Pb$ were assessed. The studies during 2005–2010 consisted of a study measuring live reindeer, the ^{137}Cs concentration distribution in reindeer summer pasture plants regionally and according to site type, the ^{137}Cs concentration distribution in reindeer meat and the publication of a time series of $^{134,137}Cs$ in reindeer meat and in reindeer herders. $^{210}Po/Pb$ concentrations were determined in different parts of the lichen–reindeer–man food chain (Solatie et al. 2006).

A study was conducted in which portable NaI-based gammaspectrometers were used to monitor ^{137}Cs in live reindeer. The aim was to improve field measurement capabilities in fallout situations (Mäntyniemi 2007). The ^{137}Cs and ^{134}Cs concentrations in lichen and reindeer have been monitored regularly in the Finnish reindeer herding area since the 1960s. The long time series of ^{137}Cs concentrations in reindeer meat and the time series of ^{137}Cs content in reindeer herders were used to examine the effective half-lives in different areas of Finland and the distribution of Chernobyl ^{137}Cs fallout. In addition, the ensuing doses from Chernobyl fallout were calculated (Leppänen et al. 2011). Currently, the average ^{137}Cs concentration in reindeer meat, 100 Bq/kg, is lower than that before the Chernobyl accident, when it was 300 Bq/kg. A study was conducted in which all 57 reindeer herding cooperatives were sampled during 2007–2009. As a result, the average of 100 Bq/kg of ^{137}Cs in reindeer meat was determined. In addition, a map of ^{137}Cs concentrations in reindeer meat in Finnish reindeer management areas was created. The results are presented on STUK's external web pages.

The ^{137}Cs concentration in reindeer meat varies throughout the year due to changes in food selection. During the summer, reindeer eat herbaceous vegetation, and in the the autumn large amounts of mushrooms – if available. In winter they prefer to eat ground and arboreal lichen. The importance of summer fodder has increased. A study was conducted in which ^{137}Cs concentrations in summer fodder plants were measured, the plants being divided according to the natural site and region. The highest concentrations occurred in plant species growing on nutrient-poor (especially potassium deficient) mires, as was also seen before the Chernobyl accident, i.e. peat land plant species in Southern Lapland (Pohjonen 2009, Skuterud et al. 2009, Anttila et al. 2011).

Strontium and caesium deviation in snow after radioactive fallout

Finland is located at high northern latitudes and is covered with snow for several months of the year. The vertical mobility of strontium and caesium in snow was studied in order to obtain information on the possible fallout situation resulting from a nuclear accident during winter. The results demonstrated that radioactive deposits on snow do not start to move down through the snowpack in significant amounts before the onset of thawing conditions. The weather has a considerable effect on the percolation rate; the contaminants are bound to the snow as long as the temperature remains below freezing, and percolation only starts when the snow warms up to the melting point. A clean, thick and dense snow cover has the greatest retarding effect on the contamination of the underlying surfaces. Percolation is faster in melting snow, but most of the contaminants can still be removed if the snow layer is thick and the decontamination is performed as soon as possible. The removal of snow is an effective, low-cost clean-up procedure for reducing the long-term radiation dose in populated areas. It is most effective when carried out before thawing, but it is also beneficial even during snowmelt (Metsäranta).

Distribution of ^{210}Pb and ^{210}Po concentrations in wild berries, mushrooms and soil in boreal forest ecosystems

The vertical distribution and activity contents of ^{210}Pb and ^{210}Po were investigated in forest soils of Scots pine dominated stands from seven different locations in Finland. The mean total inventory in the soil profile, up to 20 cm, was 4.0 kBq/m^2 (range 3.1–5.0 kBq/m^2) for ^{210}Pb and 5.5 kBq/m^2 (range 4.0–7.4 kBq/m^2) for ^{210}Po, the organic soil layer containing 45% of the total inventory of both nuclides. In both the organic and the mineral layers, the ^{210}Po/^{210}Pb ratio was close to unity, indicating a radioactive equilibrium between them. In the litter layer there was, however, a clear excess of ^{210}Po, suggesting that polonium is recycled via root uptake from the root zone to the ground surface. The activity concentration (Bq/kg) of ^{210}Pb clearly correlated with organic matter and the Fe, Al and Mn concentrations in soil, indicating that radioactive lead is associated with both humic substances and the oxides of iron, aluminium and manganese. Radioactive lead was also seen to follow the behaviour of stable lead. No systematic correlation between polonium and soil properties was seen.

The activity concentrations and distribution of ^{210}Pb and ^{210}Po in wild berries and edible mushrooms were also investigated in Finnish forests. The main study areas were located in Scots pine forests in southern and northern Finland. The activity concentrations of ^{210}Pb and ^{210}Po in blueberry and lingonberry samples decreased in the order: stems > leaves > berries (i.e. fruits). The activity ratios of ^{210}Po/^{210}Pb in the wild berry samples were mainly higher than one, indicating elevated activity concentrations of polonium in the samples. In mushrooms, the activity concentrations of ^{210}Pb and especially ^{210}Po were higher than in the fruits of wild berries. The highest activity concentration of ^{210}Pb was detected in *Cortinarius armillatus* L. (16.2 Bq/kg d.w.) and the lowest in *Leccinum vulpinum* L. (1.38 Bq/kg d.w.). The ^{210}Po activity concentrations of the whole fruiting bodies ranged from 7.14 Bq/kg d.w. (*Russula paludosa* L.) to 1 174 Bq/kg d.w. (*L. vulpinum* L.). In general, the highest activity concentrations of ^{210}Po were recorded in boletes. The caps of mushrooms of the Boletaceae family showed higher activity concentrations of ^{210}Po compared to the stipes. In most of the mushrooms analysed, the activity concentrations of ^{210}Po were higher than those of ^{210}Pb. ^{210}Po and ^{210}Pb dominate the radiation doses received via the ingestion of wild berries and mushrooms in northern Finland, while in southern Finland the ingested dose is dominated by ^{137}Cs from the Chernobyl fallout (Vaaramaa et al. 2009 and 2010).

^{90}Sr and ^{137}Cs in deposition, grass and milk in Northern Finland

Soil–grass–milk is one of the main food chains leading radioactivity in man in Finland. From 1963 onwards, dairy and farm milk and from 1972 deposition have been regularly collected at several sites in Northern Finland; some grass and AIV silage samples have simultaneously been taken. In the study the activity concentrations and decreasing rates of ^{90}Sr and ^{137}Cs were studied in the years following the atmospheric nuclear weapons testing and after the Chernobyl accident in 1986 until 2008. Transfer factors were also calculated and the ecological half-lives were estimated in the study.

^{90}Sr and ^{137}Cs activity concentrations in milk are currently below 0.1 Bq/l and 1.8 Bq/l, respectively, at all analysed sites. The concentrations of ^{90}Sr and ^{137}Cs were highest in the beginning of the 1960s due to the nuclear weapon tests, being up to 1.9 Bq/l and 37 Bq/l, respectively. Although the total deposition of ^{90}Sr and ^{137}Cs from the nuclear weapon tests was about the same throughout Finland, the highest ^{90}Sr and ^{137}Cs concentrations were found in Lapland. This was mainly due to the high proportion of peat soils and nutrient deficiency of the pasture in Lapland. The radioactive fallout in Finnish Lapland from the Chernobyl accident in April 1986 was low; ^{137}Cs was on average 1 000 Bq/m^2 and the fallout occurred before the start of the growing season. An increase in the ^{137}Cs concentrations was recorded in July 1986 and it decreased rapidly after summer 1987. There was no increase in ^{90}Sr concentrations following the Chernobyl fallout. ^{90}Sr activity concentrations from different areas were relatively similar. ^{137}Cs concentrations in Hyrynsalmi after Chernobyl were somewhat higher because of the higher fallout level in the area. A seasonal signal was shown in ^{90}Sr activity concentrations with higher values in summer, when cows are let out to the pasture or fed with fresh grass. The same signal was also found in other studies. However, a similar signal was not shown for ^{137}Cs. This discrepancy may relate to differences in soil types, grass species and fertilisation. The ecological half-lives of ^{90}Sr and ^{137}Cs in 1963–1966 were similar, being about two years. However, the half-lives for ^{90}Sr in 1975–1985 were almost twice as high as those for ^{137}Cs and six years longer in 1993–2008 (Solatie et al. 2008).

Radiological baseline studies of Talvivaara mine and the planned Sokli phosphate mine in Northern Finland

The objective of these baseline studies was to obtain a detailed understanding of the radiation levels at and in the vicinity of the Talvivaara nickel mine and Sokli site before mining actions start. The Talvivaara mining company has planned to recover uranium as a by-product. Uranium leaches, along with the main products, into the solution obtained from the bioheap-leaching process. The planned annual production would be approximately 350 tonnes and it would make Finland almost self- sufficient in uranium. In Northern Finland in the Savukoski municipality there is a plan to open a phosphate mine at Sokli. The Sokli carbonatite massif contains considerable amounts of natural radioactive substances, i.e. thorium and uranium and their decay products.

STUK carried out a radiological baseline study at the site of the planned Sokli phosphate mine and its surroundings during 2008–2010. The baseline study of the Talvivaara mine started in summer 2010 and will be completed in 2012. In the baseline studies the activity concentrations were determined in ecosystems at the Sokli and Talvivaara sites, as well as in the immediate vicinity where the mine may have a radiological impact. These baseline studies could be used in the future to assess possible impacts on the environment of natural radionuclides released during the mining and milling processes.

The highest radioactivity concentrations in Sokli were measured in the niobium ore and in the old mill tailings remaining at the site from pilot enrichment in the late 1970s. In the niobium ore the radioactivity concentrations were 8 500 Bq/kg for ^{232}Th and 2200 Bq/kg for ^{238}U. In river sediments the activity concentrations of these radionuclides varied from a few Bq/kg up to 300 Bq/kg. In reindeer meat, game meat, berries, mushrooms and in river waters the activity concentrations remained in nearly all the samples below the detection limits of the gamma spectrometric methods used. More precise radiochemical analyses of uranium isotopes were performed for different water samples. The lowest concentrations were found in river water (0.001–0.024 Bq/l) and the highest concentrations in spring water (0.0–0.02 Bq/l). ^{210}Pb and ^{210}Po were found in all analysed samples. The lowest values were found in river waters and the highest values in water moss (*Fontinalis antipyretica*), which is a common aquatic plant in Lapland and known to be a good bio-indicator for heavy metals. High amounts of ^{210}Pb and ^{210}Po were also found in reindeer lichen (*Cladina rangiferina*), which is the main food plant of reindeers, and in beard moss growing on spruce and pine branches and in boletes. The activity concentrations of ^{222}Rn in groundwater samples varied between 30–110 Bq/l. In river water samples, radon concentrations were below the detection limit of

30 Bq/l. The results of this project have been published in project reports and disseminated for the professional audience.

Changes in ^{137}Cs activity concentrations with time in various fish species and water in lakes of Finnish Lapland

The radioactive fallout in Finnish Lapland from the nuclear reactor accident in Chernobyl in 1986 was low, being 1 000 Bq/m^2 on average for ^{137}Cs. The enrichment of radionuclides in a special Arctic food chain such as lake water–fish–man is, however, effective and the Arctic and sub-Arctic environment is very vulnerable. ^{137}Cs could still be measured two decades after the accident in various fish species of the lakes. Fish and freshwater samples were collected from Lake Inari and Lake Apukka, which represent two different types of lakes from different drainage areas, Paatsjoki and Kemijoki in Finnish Lapland. The aim of this study was to determine how the activity concentration of ^{137}Cs in the lakes of Lapland has changed over time and what the current situation is. The ecological half-lives and the environmental factors influencing the long-term behaviour of ^{137}Cs were estimated, correlations between fish and lake water were analysed and concentrations factors were calculated.

The highest ^{137}Cs activity concentrations were measured in pike (*Esox lucius*), perch (*Perca fluviatilis*) and trout (*Salmo trutta*) and the lowest in whitefish (*Coregonous lavaretus*) and roach. In the 1960s, ^{137}Cs activity concentrations varied between 140 and 360 Bq/kg f.w. in pike and trout and between 60 and 120 Bq/kg f.w. in whitefish in Lake Inari. After the Chernobyl accident in 1986, ^{137}Cs activity concentrations varied between 210 and 320 Bq/kg f.w. in pike and perch, and 60 and 70 Bq/kg f.w. in vendace *(Coregonus albula)*, trout and whitefish. In the last decade, ^{137}Cs activity concentrations varied between 6–36 Bq/kg f.w. in all the studied species. In 1988–2005, ^{137}Cs activity concentrations in freshwater ranged from 0.3 to 22 Bq/m^3 in Lake Inari and from 0.7 to 12 Bq/m^3 in Lake Apukka. Estimated ecological half-lives in Lake Inari in 1987–1996 were 3.0 years in pike, 4.5 years in perch and 2.2 years in whitefish, and the respective values in 1997–2007 were 9.9, 20 and 6.7 years. In Lake Apukka the estimated ecological half-lives in pike, perch and roach were 4.6, 3.2 and 4.3 years in 1987–1996 and 25, 28 and 21 years in 1997–2007.

Due the enrichment of radionuclides, ^{137}Cs activity concentrations were highest in predatory fishes. The ecological half-lives were of the same order of magnitude (2.2–4.5) in both lakes 8 years after the Chernobyl accident. ^{137}Cs activity concentrations in freshwater and in fish meat were higher in Lake Inari than in Lake Apukka, indicating the greater global fallout of ^{137}Cs in Lake Inari. This is one reason why Lake Inari has not reached (1997–2007) the same (long) ecological half-lives. Another reason for the long half-lives in fish meat in Lake

Apukka is a characteristic of the lake vicinity that maintains the elevated levels year after year. The results have been published in conference proceedings.

Caesium-137, polonium-210 and lead-210 concentrations in seals from Arctic seas, the Baltic Sea and Lake Saimaa in 1995–2009

Seals are important indicator species of the current state of the environment. The aim of this study was to provide baseline data on radionuclide concentrations and their distribution in seals (*Phocida*) in three environments: marine, brackish and freshwater ecosystem. A total of ninety-nine seals were caught in Arctic Seas from 1995–2004 and carcasses or organ samples were delivered to STUK by the Murmansk Marine Biological Institute (MMBI), Russia and by Akvaplan Niva, Norway. Nine seals from the northern Baltic Sea, Gulf of Bothnia were obtained during 1998–2007 by the Finnish Food Service Authority Evira. Organ samples of 54 protected Lake Saimaa seals were obtained by special permission from 2003 to 2009 by the Natural Heritage Services of the National Board of Forestry, Finland.

In Arctic seal pups the mean radionuclide ^{137}Cs concentrations varied between 0.18 and 0.60 Bq/kg f.w. in muscle, heart, liver, kidney, spleen, pancreas, cartilage, cartilaginous bone, bone and blubber. In adult seals the mean ^{137}concentrations varied between 0.21 and 0.34, ^{210}Po concentrations between 35 and 220 and ^{210}Pb concentrations between 0.4 and 1.1 Bq/kg f.w. in muscle, liver and kidney.

In the Baltic seals the lowest mean ^{137}concentration was 1.91 in blubber and the highest 86.4 Bq/kg f.w. in cartilaginous bone. ^{210}Po concentrations in seal liver, kidney and muscle were 19.3, 15.1 and 4.0 Bq/kg f.w. and ^{210}Pb concentrations were 0.8, 0.7 and 0.2 Bq/kg f.w., respectively.

The mean radionuclide ^{137}Cs concentrations in Lake Saimaa ringed seals (*Phoca hispida saimensis*) varied between 63.5 and 90.0 Bq/kg f.w. in muscle, liver and kidney, bone, spleen and pancreas. The ^{137}Cs concentrations in Lake Saimaa ringed seals (*Phoca hispida saimensis*) decreased slowly from 2003–2009, and the ecological half-life was 4.2 y. (Ylipieti J, Solatie D. ^{137}Cs concentrations in Saimaa ringed seals during 2003–2009). In Lake Saimaa the results were collected in two time series from 2003–2004 and 2006–2007. During 2003–2004, ^{210}Po concentrations varied between 5.5 and 49 and ^{210}Pb concentrations between 0.3 and 2.7 Bq/kg f.w. in muscle, liver, kidney, spleen and bone, and the respective ranges during 2006–2007 11.6–71 and 0.9–18.3 Bq/kg f.w.

The highest ^{137}concentrations in the Arctic Sea pups were measured in muscle, cartilage, cartilaginous bone and other soft tissues, and the lowest in bone and blubber. ^{137}concentrations were low both pups and adult seals in the

Arctic Sea, but mean values were higher in the adult seals in all studied organs. In the Baltic Sea, ^{137}concentrations were highest in same organs as in the Arctic Sea pups, especially in muscle, cartilage and cartilaginous bones. Very low ^{137}concentrations were recorded in blubber in the Baltic Sea. In Lake Saimaa, ^{137}concentrations were of the same order of magnitude in both pups and adult seals. The highest value was 180 Bq/kg f.w.

Activity concentrations of ^{137}Cs were significantly higher in the freshwater ecosystem of Lake Saimaa and in the low salinity brackish water ecosystem of the Baltic Sea than in the Arctic seas. The contribution to lower concentrations from the melting effect of the global sea streams and the salinity of the water probably reduces the activity concentrations of ^{137}Cs in living species. The results also indicate that the ^{137}Cs concentrations in Saimaa ringed seals decreased consistently not only in muscle, but also in liver and kidney, during the study period. A similar trend was found in the correlation between seal weight and the ^{137}Cs concentrations, which indicates a high accumulation of ^{137}Cs in this species. Concentrations of the radionuclide ^{210}Po were highest in Artic seals. The living environment mainly determines the caesium, polonium and lead concentration levels, and they change over time. To date, the results have been disseminated only in conference presentations.

Radiocaesium in wild berries and natural herbs in Northern Finland

The impact of the Chernobyl deposition can still be detected in products of natural origin, i.e. freshwater fish, wild mushrooms, game meat, reindeer and forest berries. To remain aware of the activity concentrations and their variations, STUK still has extensive analysis programmes for natural produce. The activity concentrations of ^{137}Cs in various wild berries and natural herbs at different sites in Northern Finland have been determined before and after the Chernobyl accident. The results have also been processed statistically and the aggregated transfer parameters calculated.

The mean ^{137}Cs activity concentration before the Chernobyl accident in 1986 was 15 Bq/kg f.w. in bilberry (*Vaccinium myrtillus*), 8.6 Bq/kg f.w. in lingonberry (*Vaccinium vitis-idaea*) and 38 Bq/kg f.w. in cloudberry (*Rubus chamaemorus*). A few years after the accident the maximum values were 45, 79 and 245 Bq/kg f.w., respectively. ^{137}Cs activity concentrations varied in cranberry (*Vaccinium oxycoccos*) from 1.4 to 36 Bq/kg f.w. in 1988–2006. Calculated means of TFs were 0.0037–0.0063 m^2/kg f.w. in bilberry, 0.0038–0.0045 m^2/kg f.w. in lingonberry and 0.018–0.025 m^2/kg f.w. in cloudberry. The mean ^{137}Cs activity concentration was 47 Bq/kg d.w. in birch leaves and 270 Bq/kg d.w. in willowherb. After the accident the maximum values were 620 Bq/kg d.w. in birch and 1 290 Bq/kg d.w. in willowherb.

The data indicate that cloudberry, which is a species typical of Arctic ecosystems, has the highest ^{137}Cs activity concentrations and is relatively sensitive to radiocaesium deposition compared to the other species. Cloudberry and cranberry grow on wet, highly organic peatlands, where the conditions lead to high radiocaesium uptake by plants from the soil. The bilberry and cowberry grow on dry land, mainly in forest where the organic layer is thin and sand is often present under the organic horizons. The cloudberry and the studied natural herbs seemed to be more sensitive to radiocaesium than bilberry and lingonberry. The ^{137}Cs concentrations in natural herbs were higher than in wild berries. The reduction in the ^{137}Cs content of Arctic berries over time is slow. To date, the results have been disseminated in international conferences only.

Radiocaesium concentrations in humus layers in Finland, NW Russia and Baltic countries

The situation resulting from the Chernobyl fallout in 1987 was compared to that in 2000–2001 in Finland and NW Russia and that in 2003 in the Baltic countries. Altogether, 786 humus (0–3 cm layer) samples were collected during 2000–2001 in the Barents Ecogeochemistry Project, and 177 samples in the Baltic countries in 2003. Nuclides emitting γ-radiation in the 0–3 cm humus layer were measured. The aims of this study were first to analyse the ^{134}Cs and ^{137}Cs activity concentrations (Bq/kg d.w.) in the humus layer samples, and second to produce an inventory of ^{137}Cs in Bq/m^2 in order to be able to compare the fallout situation in 1987 with that in 2000–2001 in Finland and NW Russia and in 2003 in the Baltic countries.

The radionuclide ^{137}Cs was detected in the humus layer at all 988 sampling sites, while ^{134}Cs was still present at 198 sites. No other anthropogenic nuclides emitting γ-radiation were detected, but low levels of ^{60}Co, ^{125}Sb and ^{154}Eu isotopes were found at 14 sites. In Estonia the average ^{137}Cs inventory was 550, in Latvia 630 and in Lithuania 720 Bq/m^2. The area most affected by the Chernobyl accident was the NE corner of Estonia. An exceptionally high value of 12 300 Bq/m^2 was omitted when calculating the mean for Estonia. ^{137}Cs inventory values of 30 000 and 53 000 Bq/m^2 were obtained for two locations in South Finland. The high 3 000–22 000 Bq/m^2 inventory class was based on 53 sampling sites, and the class below 3 000 Bq/m^2 on 322 sampling sites.

Fifteen years after the Chernobyl accident, the radioactive nuclide ^{137}Cs was and still is the most significant fallout radionuclide in the environment and in food chains. The results demonstrate that the fallout can still be detected in the uppermost humus layer in Northeast Europe (Ylipieti et al. 2008).

Cosmogenic isotopes ^{7}Be and ^{22}Na as atmospheric tracers

STUK's airborne radioactivity monitoring network consists of eight monitoring stations located in different cities throughout the country. The monitoring stations have been established for emergency preparedness purposes to monitor anthropogenic airborne radioactivity. Aerosol samples are collected onto glass fibre filters on a weekly basis. In normal operation, the concentrations of natural radioisotopes are monitored. The cosmogenic isotopes have been recognised as natural tracers for atmospheric dynamics since the late 1950s. The studies have concentrated on improving our understanding of the behaviour of cosmogenic isotopes and their application to verify calculations from atmospheric models (e.g. GCM models). Long-term observations have provided a tool to study the large-scale climatic impact on the climate in Finland. In addition, the demand to detect low concentrations of ^{22}Na has led to developments in detection techniques. (Lucenius 2008, Usoskin et al. 2009, Zhang et al. 2011).

The ground-level ^{7}Be and ^{22}Na concentrations were found to be a combination of atmospheric production and transport. The time series of the isotopes were studied with novel time-series analysis tools. Several interannual periodicities of 2.5, 3.5, 4.8, 7.8, 11, ~12–14 and ~22–25 year time scales were found in the time series. These periodicities were assigned to NAO/AO and SOI climatic phenomena and 11-year solar cycle variations. The composition and strength of periodicities depend on the location of the station. The $^{7}Be/^{22}Na$ ratio also showed distinctive annual variation, which may be related to variation in the boundary layer (Leppänen et al. 2010, Leppänen et al. 2011).

The ^{7}Be observations were used in a study where an atmospheric production model was combined with a general circulation model (GCM). The model calculations were compared with ^{7}Be observations in Europe, Canada, the USA, Australia and New Zealand. The results demonstrated that global ^{7}Be observations can be used to validate climate models (Usoskin et al. 2009).

Radioecological research in the Barents Sea

From 1993 to 1996, radioecological research was also performed in the Arctic Sea areas of NW Russia. The Regional Laboratory in Northern Finland re-started cooperation with the Murmansk Marine Biological Institute (MMBI) in 2006. This cooperation led to two joint expeditions to the Barents Sea in 2007 and 2009. Samples of sediment, sea water and fauna were collected during these expeditions. The aim was to gain more information on the levels and origin of caesium and plutonium in the Barents Sea. Gammaspectrometric and radiochemical polonium and plutonium analyses were performed on sediment and fish samples at STUK, while MMBI performed gammaspectrometric analyses and radiochemical strontium analyses on sediment and water samples.

The measurements of concentrations provide data to study radioactive contamination in the Barents Sea. The nuclide ^{137}Cs and $^{238,239,240}Pu$ ratios in sediment samples provide a tool to estimate the contributions of radioactivities from different sources (Matishov et al. 2009).

The results revealed low concentrations in fauna, water and sediment samples throughout the Barents Sea. The studies indicate that the main source for ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ isotopes was global fallout. However, in few cases, indications of other sources than global fallout were found (Leppänen et al. Submitted).

Arctic monitoring and assessment programme (AMAP)

The Arctic Monitoring and Assessment Programme (AMAP) is a group working under the Arctic Council (AC). The arctic countries include the USA, Canada, Russia, Norway, Sweden, Finland, Iceland and Denmark. The Arctic Council Ministers have requested AMAP to produce integrated assessment reports on the status and trends in the conditions of Arctic ecosystems; to identify possible causes for the changing conditions; to detect emerging problems, their possible causes, and the potential risk to Arctic ecosystems including indigenous peoples and other Arctic residents; and to recommend actions required to reduce the risks to Arctic ecosystems. One of the key pollutants examined in the AMAP programme is radioactivity. One of the key issues is the effect of global warming on Arctic ecosystems.

The 3rd AMAP Radioactivity Report of the Radioactivity Expert Group (AMAP, 2010) contains information relating to the levels and distribution of radioactive contamination and the radiological consequences of radioactivity in the Arctic. In addition, consideration is given to the consequences of accidents and other possible future sources of contamination in the Arctic. New data concerning actual and potential sources of radioactive contamination in the Arctic are also presented. The report is a successor to the 1st and 2nd AMAP assessments published in 1997 and 2004. The AMAP provided several recommendations for continued monitoring of the status of the Arctic environment and the management of potential nuclear and radiation threats.

6.6 Preparedness for radiological threats and emergencies

6.6.1 Remote detection and nuclear security

Nuclear security was introduced to STUK in the aftermath of the September 11 terrorist attacks. Special funding was dedicated to the development of in-field radiation measurement techniques for cooperation between police and STUK.

In the 1990s, STUK had developed a response against accidents. However, detecting a small signal with a fast analysis and response time is a different domain and requires a new approach.

Mobile measurements are of crucial importance for nuclear security. Portal monitoring or other measurements at fixed locations cannot alone provide credible deterrence or a sufficient response against criminal or unauthorised acts involving nuclear or other radioactive materials. In a country like Finland with a small population but long borders, good cost efficiency of mobile measurements is important in building a nationwide response.

The data processing related to mobile measurements requires considerable knowhow, because the observations have to be associated with geographical locations. A well-designed database is the only possibility to handle the massive information flow. In 2006, STUK and Helsinki University of Technology launched a joint R&D project to create a database that can handle different types of spectra. This database, known as LINSSI, is particularly well suited to mobile spectroscopy.

During 2005–2010, several research projects were carried out related to nuclear security. For example, an air sampler and a real-time radiation measurement system were designed for an Unmanned Aerial Vehicle (UAV). Such capability is also very useful in the aftermath of a nuclear disaster. However, the major R&D efforts of the laboratory were devoted to mobile systems in vehicles and in backpacks. These projects are reviewed below.

SONNI – a moving laboratory

A moving laboratory, known as SONNI (Sophisticated ON-site Nuclear Identification), was built in 2003–2005. The key design requirement was the timeliness of the spectroscopic data; the measurement results must be available at the headquarters in real time. The vehicle has four gamma spectrometers that produce data at 4 s intervals. In 2008–2010 the technology of SONNI was upgraded. New data processing software had to be developed for the crew and for the reachback centre. Later, this effort was very valuable in a more systematic software development project for in-field applications (see later for VASIKKA).

SONNI has a unique capability for air sampling. This is very important during the early stage of a nuclear event, be it malicious or accidental. STUK has sold the product rights of the vehicle, and SONNI is now commercially available.

SONNI has turned out to be highly invaluable to secure major public events. The vehicle was first used operationally in 2005 to support the police in the security arrangements for the European Championship in Athletics, Helsinki. Since then, SONNI has had numerous missions covering, for example, the Finnish EU leadership, several VIP visits and environmental monitoring in Estonia.

VASIKKA – a backpack for first-line officers

Spectroscopic measurements are challenging to perform correctly in field conditions. The standard laboratory equipment may fail or can be difficult to use. A software project was launched in 2006 to develop a spectroscopic system that would provide high-quality gamma spectra without the presence of a nuclear scientist. The development led to software known as VASIKKA.

VASIKKA performs data acquisition with different detectors, such as $LaBr_3$, NaI and HPGe. The spectrum analysis is based on hypothesis testing. It is assumed that a certain nuclide is present in the spectrum; the goal of the analysis is to test this hypothesis at a certain risk level (10^{-6}). As a result of the analysis, VASIKKA returns the peak areas ($\boldsymbol{A}$) and their uncertainties (σ). The ratio $\boldsymbol{A}/\sigma$ is proportional to the signal strength and is very useful in the generation of an alarm.

VASIKKA writes the data to a local or to a remote LINSSI database. A special algorithm, implemented in *mufi* software (multiplet fitting) and later in its Java version *JMufi*, was developed to keep the system stable in terms of energy response. The software continuously analyses the position (channel) of certain spectral structures, such as the K-40 peak or the lanthanum lump, and then compensates for the possible gain change caused by temperature variation or other disturbances. Prototype backpacks were assembled and the in-field capability was demonstrated successfully. This led to the commercialisation of VASIKKA, and the backpack is now a rugged measuring system for police, customs and other operational units. In the aftermath of the Fukushima accident, VASIKKA was used to screen aircraft and their cargo. *In-situ* spectroscopy was also carried out in Narita, Japan, for fallout estimation.

SNITCH – reachback software

An in-field mission for radiation detection includes several tasks related to measurement, analysis and response. The analysis of the spectra and a related expert view on the interpretation of the results can be efficiently performed in the headquarters provided that all relevant data can be transferred in a timely manner. Reliable spectrum analysis, in particular, requires knowledge in nuclear physics, and the responsibility for resolving alarms – false, innocent or true – cannot therefore be passed to the police officers or to other first responders. The expert support, also known as reachback, includes automated and interactive data processing services, feedback reports and advice to the operational units. The reports can be text messages, emails with pdf attachments, the upgrade of a web page or immediate voice communication, either using commercial GSM services or secure Tetra phones.

A small-scale reachback service has been operational at STUK since 2005. This software was intended for handling alarms from SONNI on digital maps. In 2007, a more systematic approach was taken under an EU programme on Fight Against Crime. Software, known as SNITCH (Spectral Nuclide Identification Technology for Counterterrorist and Hazmat units), was developed to demonstrate the concept. Since early 2011, SNITCH has been operational at STUK. The experience is good; well-trained reachback personnel can essentially improve the efficiency of a field mission. The concept works for nuclear safety, security and safeguards.

UAS – Unmanned Aerial Systems

Unmanned aerial vehicles, UAVs, may provide an appropriate platform for equipment needed in different types of radiation surveillance mission. For example, in a nuclear accident, such as in the Fukushima case, they may serve as a bull's-eye solution for radiation measurements close to the damaged plant or in the environment. STUK has previously investigated the use of a mid-sized Ranger UAV for radiation reconnaissance (Kurvinen et al. 2005, Kurvinen et al. 2008). Recently, equipment for radioactive particle sampling (Peräjärvi et al. 2008a) and radiation measurements (Pöllänen et al. 2009c, Pöllänen et al. 2009d, Pöllänen et al. 2009e) have been mounted and tested in a Mini-UAV. The platform and the measurement equipment were found to be viable for radiation surveillance.

6.6.2 Non-destructive analysis – NDA

A project on the development of non-destructive analysis (NDA) of samples was started with a feasibility study in 2007. The official NDA project was initiated at the beginning of 2008 and it will be completed at the end of 2011. Its main work packages are PANDA, SPANDA and MiniPANDA. The primary outcome of these tasks together with the experimental validation are summarised below.

NDA techniques are used both in the laboratory and in field conditions. A sample may be so valuable, or subject to some other constraints, that only NDA techniques can be performed for its investigation. NDA techniques are normally used because of simplicity and time requirements – no sample processing is required before the measurement. This usually also means less equipment to be carried along.

PANDA

PANDA (Particles And Non-Destructive Analysis) is a comprehensive development platform for novel spectroscopic measurement systems rather than a device tailored for a specific purpose. PANDA is designed to find particles in a sample and to characterise them using advanced alpha-gamma coincidence techniques with event-mode data acquisition. This capability is very useful for nuclear forensics, because the individual particles tell the origin, while the average activity of the sample is not informative.

PANDA consists of two vacuum chambers that are connected with a gate valve. The loading chamber is used to pump the sample down into a vacuum. The pump-down from 1 atm to 10^{-9} atm can be made slowly using a precision needle valve. When a high vacuum is reached the gate valve can be opened and the sample, installed on the tip of a linear feedthrough, moved into the measurement chamber. The measurement chamber is always in high vacuum and it has two measurement positions. The first position, which is already in operational use, hosts large detectors primarily meant to screen the samples.

Position-sensitive screening for alpha particle-emitting radionuclides is accomplished using a 64×64 mm^2 DSSSD detector that has a pixel size of 2×2 mm^2. A broad energy germanium detector, with a crystal diameter of 70 mm and a thickness of 21 mm, is installed opposite the DSSSD detector. The orthogonal distance between the detectors can be varied from a few millimetres to several centimetres. A sample to be screened, such as a swipe, is moved between the detectors using the linear feedthrough. The centralised event-mode data acquisition system allows versatile views on the collected data. As an example, sophisticated coincidence gating and half-life studies are possible.

The second measurement position is primarily intended for studies on individual particles and radiochemically processed samples. It hosts a small silicon-drift detector (SDD) with superior energy resolution. This detector has been installed on the tip of a second linear feedthrough moving vertically. In this way the detector can be moved to the vicinity of any interesting spot on the sample. A feasibility study related to the used prototype SDD has been completed. Since the detector has a very thin entrance window, it also provides the capability to detect low energy conversion electrons from the samples. Signals registered by the SDD are collected with VASIKKA software and they are directly stored in a LINSSI database for later analysis.

For more detailed information about PANDA, see Peräjärvi et al. (2009) and Turunen et al. (2010b). The article by Turunen et al. (2011) describes the application of PANDA in studies on thin Mylar foils.

SPANDA

The handling of data generated by the event-mode data acquisition system of PANDA is a challenge. Each recorded event also contains a time stamp. In addition, these data are linked with administrative information such as the sample description and settings used during the measurement. Thus, it is clear that effective data handling tools have a crucial role in the analyses. In PANDA, all data are saved in a LINSSI database with some additional tables for event-mode data.

The data acquisition system in PANDA saves the event-mode data in binary format supported by the acquisition control and online monitoring software. These resulting binary event files are converted to an easily readable Extensible Markup Language (XML) format. Then, these XML files are loaded into a LINSSI database based on MySQL. To reduce the amount of data saved in the database, the loading script allows the setting of criteria for the events to be saved. As an example, it is possible to save only those events where both the front and the back strips of the DSSSD have recorded a clear signal, or in addition, the HPGe signal could also be required in the event. Criteria such as these drastically reduce the amount of data loaded, and thus significantly speed up both the loading and analysis processes.

Traditional analysis software can only handle spectral data. Therefore, software is needed for the generation of spectra from the event-mode data saved in the database. For this purpose, software known as SPANDA was developed. SPANDA reads the event information and saves it back in a spectrum format. Typically, various spectra with different properties are created from the same event-mode data set. The criteria for querying can easily be changed through a graphical user interface. Independent DSSSD gain matching and particle locating algorithms are implemented in SPANDA. The gain matching algorithm is important while creating alpha particle hitmaps or spectra employing several DSSSD pixels. Finally, the generated spectra are fetched from the database and analysed with programs such as Aatami (gamma) and Adam (alpha).

The analyses are performed separately for each spectrum. The analysis results are saved back to the database and linked with the original data. The parameters of the queries used while performing the analysis are also stored. The LINSSI database has an advanced structure for handling several measurements and analyses related to one sample. For more information, see Turunen et al. (2010a).

MiniPANDA

Ideas tested successfully in PANDA are useful for the development of independent applications. One such system is an alpha/beta/gamma coincidence setup for sample analysis. Based on experience with PANDA, a streamlined easy-to-use device called MiniPANDA was built. It allows simultaneous measurements of low background gamma-ray singles, alpha particle singles and alpha-gated gamma-ray spectra. Measurements are performed inside a lead castle at air pressure. Alpha spectrometry is accomplished using a 2 000 mm^2 CAM detector. A broad energy germanium detector, with a crystal diameter of 70 mm and a thickness of 21 mm, is installed opposite the CAM for gamma and X-ray spectrometry. Data are collected at short intervals using VASIKKA and they are directly stored in a LINSSI database. The data management is controlled LIBS software (LINSSI Information Browser), which is a powerful interface between the LINSSI database and the analysis.

Evaluations

An analysis procedure for PANDA samples was developed using a nuclear bomb particle from the Thule accident (Peräjärvi et al. 2011). PANDA was then further tested and developed with large area swipe samples provided by the IAEA (reported in TTL-TECDOC-2011-006). An air sample containing ^{241}Am was successfully measured and analysed with PANDA (TTL-TECDOC-2011-003). The PANDA test programme will be completed at the end of 2011.

A nuclear bomb particle from the Thule accident containing 1.6 ng of Pu was investigated non-destructively with PANDA. Alpha-gamma coincidence counting was shown to be well suited to non-destructive isotope ratio determination. Because of the very small background, the 51.6 keV gamma rays of ^{239}Pu and the 45.2 keV gamma rays of ^{240}Pu were identified, which enabled isotopic ratio calculations. In the present work, the ^{239}Pu/(^{239}Pu + ^{240}Pu) atom ratio was determined to be 0.950 ± 0.010. The uncertainties were much smaller than in the previous more conventional non-destructive studies on this particle. The results are also in good agreement with data from the destructive mass spectrometric studies obtained previously by other investigators. It is noteworthy that the alpha-gated gamma-ray technique tolerates the presence of non-alpha decaying activation or fission products in the sample, i.e., they do not complicate the analysis of alpha particle emitting nuclides.

A variety of safeguards and forensic analyses are carried out for the swipe samples. Therefore, the usability of the PANDA device in the non-destructive analyses of the swipes provided by the IAEA was tested. The swipe samples were measured as such without any pre-processing. The analyses were performed without knowing the plutonium and uranium isotopic ratios. The total plutonium and uranium masses were also not utilised; the samples were treated as fully unknown. The analyses proved that PANDA is very effective for screening swipe samples containing ^{241}Am, ^{239}Pu or ^{240}Pu. The spatial activity distribution of such samples can be determined rapidly, in minutes or hours depending on the activity. If single radioactive particles are present, their locations can be determined as well. The $^{239}Pu/^{240}Pu$ isotope ratio measured by PANDA was correct within the reported uncertainty limits. However, the uncertainties given by PANDA were large; the main reason being the low statistics related to the attenuation of the alpha particles in the cotton matrix. The geometry of the cotton swipe samples is not optimal for PANDA analysis. The accuracy of the results was significantly limited by the large thickness of the sample matrix. In the worst case, most of the alphas were absorbed in the sample material and only less than 10% reached the sample surface.

The PANDA device was also used to measure an air sample collected in Helsinki between 22.12.–23.12.2010 that contained ^{241}Am. A fair agreement between three methodologies was obtained. Using gamma spectrometry the americium activity was determined to be 1.0 ± 0.5 Bq and with alpha spectrometry 1.1 ± 0.2 Bq. The corresponding acquisition times were 24.8 h and 3 h respectively. In the gamma measurement the main part of the uncertainty comes from the poorly known detection efficiency (position of the particle with respect to the detector). In PANDA, this sample was counted for 18.4 h and its americium activity was determined to be 1.015 ± 0.077 Bq (1σ).

6.6.3 Alpha spectrometry research programme

Systematic development of radiation measurement techniques is of major importance in environmental radiation monitoring and preparedness as well as in nuclear safety, security and safeguards. The development of alpha spectrometry for various applications was one of the key domains in 2005–2010. The aim of the programme was to improve STUK's expertise and preparedness to rapidly identify and detect alpha-particle emitting radionuclides in the laboratory and in the field in the case of a nuclear incident/accident or malevolent use of alpha emitters. In addition, the analytical processes used in the Nuclide Analytical Laboratory of STUK benefitted the development.

A great number of original scientific articles (13), conference proceeding articles (8) and other papers (9) were published in the alpha spectrometry research programme. Posters, talks in (inter)national conferences and other presentations, demonstrations, training courses as well as the development of measurement/sampling equipment and software tools have been other outcomes.

Sampling

Appropriate sampling techniques have been developed for non-destructive alpha spectrometry. Special techniques/methods were introduced to produce appropriate samples for alpha spectrometry without radiochemical processing, which enables rapid measurements. The techniques are suitable for air samples (Pöllänen and Siiskonen 2006a), swipes (Ihantola 2009, Pöllänen and Siiskonen 2007) and liquid samples (Vesterbacka and Pöllänen 2010). The new solutions were successfully used, for example, at the Vancouver Olympic Games (DAAFS project, Hoffman et al. 2010) and in Helsinki-Vantaa and Tokio-Narita airports to monitor contamination of the air and aircraft during the Fukushima accident. The equipment was also mounted in STUK's moving laboratory SONNI (Pöllänen and Siiskonen 2008a). The use of the sampling systems is envisaged in nuclear security and safeguards.

Simulations

The phenomena influencing the detection of alpha particles from different type of samples and in different data acquisition conditions (vacuum/no vacuum) must be well understood for equipment design and data analysis. For this purpose, a computer program known as AASI (Advanced Alphaspectrometric Simulation, Siiskonen and Pöllänen 2005, Siiskonen et al. 2008a) was developed. AASI is freely available through STUK's Internet pages. The software has been downloaded more than 150 times, and is used in different applications such as training, research and technical development. Another program, AASIFIT (Advanced Alphaspectrometric Simulation and FITting, Pöllänen et al. 2009a), was developed to cope with complex alpha spectra. AASIFIT unfolds alpha spectra with the aid of the family of the peaks generated by the simulations (AASI program).

Data Acquisition

Software known as α-Vasikka was developed for data acquisition. α-Vasikka is able to produce the alpha spectra and related meta data in XML format, which is directly compatible with the LINSSI database. This means that the spectra can be saved over a network (LAN or wireless) to a remote database where advanced analysis processing can be launched through SNITCH. α-Vasikka was successfully taken into operational use in a Canadian project (DAAFS) and it was used at the Vancouver Olympic Games with data processing in Ottawa.

Operational Spectrum analysis

A novel spectrum analysis tool ADAM (Advanced Deconvolution of Alpha Multiplets) was developed to cope with complex alpha spectra containing overlapping peaks of different nuclides. ADAM was thoroughly tested by analysing a large number of simulated and measured spectra. The program was demonstrated to give unbiased peak areas and statistically correct uncertainty limits. This applies regardless of the peak areas and the number of unknown parameters during the fitting. In addition, ADAM performs reliable deconvolution of multiplets. This opens the way for the determination of isotope ratios such as $^{239}Pu/^{240}Pu$, which is crucial for nuclear safeguards. The quality of the ADAM results is based on a full covariance calculus, which is mathematically a very demanding task. The peak shape model of ADAM is a convolution of a Gaussian distribution with low-energy side exponentials, and different radionuclides can have different peak shapes. ADAM can also take into account coincidences between alpha particles and other particles (Pöllänen and Siiskonen 2005, Siiskonen and Pöllänen 2006).

ADAM may have an impact on routines in the analytical laboratories. Part of the expensive mass spectrometry studies can be replaced with much simpler alpha spectroscopy, which must nevertheless be performed because of possible ^{238}U contamination of the plutonium samples. In the near future, ADAM will be in routine use at the Laboratory of Radionuclide Analytics of STUK.

Portable alpha spectrometry without vacuum

Feasibility studies showed that data acquisition can be performed with good energy resolution even at ambient air pressure. Prototype equipment known as ADONIS (ADvanced ON-site Investigation using alpha Spectrometry) was developed. This novel approach will open completely new application areas for alpha spectrometry. It is expected that the equipment could be utilised in nuclear safety, security and safeguards. Preparedness and environmental surveillance are other options.

6.6.4 CTBT support – ultra pure Xe standards

In underground nuclear explosions, gaseous species such as xenon have the highest chances of escaping to the atmosphere. In practice, radionuclide surveillance of the underground tests of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) rely on the detection of ^{131m}Xe ($T_{1/2}$ = 11.84 d), ^{133m}Xe ($T_{1/2}$ = 2.19 d), ^{133}Xe ($T_{1/2}$ = 5.243 d) and ^{135}Xe ($T_{1/2}$ = 9.14 h) because of their suitable half-lives (not too long or short) and large production cross sections in fission.

Due to the large scatter of experimental results on the conversion coefficient of ^{133m}Xe and because of its utmost importance for verification of the Treaty, we re-measured its decay using an electron-transporter spectrometer and a planar HPGe detector. The sample containing ^{133m}Xe was produced by means of proton-induced fission using an ion-guide-based on-line mass separator at the Accelerator Laboratory of the University of Jyväskylä, Finland. The deduced K and L+M+… shell conversion coefficients, α_K = 6.5(9) and $\alpha_{L+M+\ldots}$ = 2.9(4), agree within the uncertainty limits with the theoretical values and remove the inconsistencies between the previous experimental studies on ^{133m}Xe (Peräjärvi et al. 2008b).

Because of the above-discussed central role of these xenon isotopes and isomers, they are also needed as calibration sources by the CTBTO. In Peräjärvi et al. (2010a) we reported for the first time a method for producing pure ^{133m}Xe sources. This achievement required a new milestone in mass purification. This work was carried out at the Accelerator Laboratory of the University of Jyväskylä; it was acknowledged by the New Scientist magazine in 2010 (April 10, p. 6). To complete the development, the production of ^{131m}Xe and ^{135}Xe samples was successfully demonstrated at Jyväskylä in summer 2010. Note that from the mass separation point of view, ^{131m}Xe and ^{135}Xe samples are more straightforward than ^{133m}Xe or ^{133}Xe samples.

In Peräjärvi et al. (2010) we also reported that the xenon was retained well in aluminium, i.e., the foil had to be melted before a significant xenon release occurred. Since gaseous xenon samples are also required by the CTBTO, the release properties of xenon from graphite were studied in summer 2010. The outcome was that graphite is a perfect material for use. The currently prepared xenon article also includes the results of these studies and it ends with a discussion on how the actual foil-to-gas-container conversion could be efficiently accomplished.

The status of the entire project was summarised in a review article ordered by Hyperfine Interactions magazine in 2010 (Peräjärvi et al. Submitted).

6.6.5 Decision support systems for nuclear emergencies

KETALE (Centralised data system for management of dispersion and dose calculation results)

The Laboratory of Environmental Surveillance and Preparedness in co-operation with the Finnish Meteorological Institute (FMI) developed a centralised system for managing the results of dispersion and dose calculations, which was given the name KETALE. The first version of KETALE was published in 2008. Since then it has been continuously developed and extended in scope. Today it has become a key element of STUK's emergency preparedness. KETALE provides users with easy access to distributed modelling applications (e.g. the near-range dispersion models of RODOS, the long-range dispersion model of FMI) and allows the results to be displayed on an interactive Web map. Suitably portrayed results can be included within various summary or analysis reports. The KETALE system also facilitates the simulation of measurements during exercises and the preparation of recommendations. All information is instantly accessible to all users by means of a web browser. Currently, KETALE is the main communication and data exchange platform between STUK and the FMI. Along with the development of KETALE, the emergency procedures for dispersion and dose calculation have been revised. The KETALE system improved the quality of the dispersion and dose calculation products, streamlined the information exchange between STUK and the FMI and fostered better coordination between the emergency organisations of these two institutes.

RODOS (Real-time On-line Decision Support system for nuclear emergencies)
STUK has been involved in the RODOS project almost since its beginning. The Laboratory of Environmental Surveillance and Preparedness has been maintaining and operating the software, and provided user guidance. The Laboratory actively participated in the re-design of the RODOS software during the EURANOS project, tested the various beta releases, and took the system into operational use in 2010. The RODOS system has been operating in a continuous mode on a 24/7 basis since 2010. In this setup, the dispersion situations at both domestic NPP sites are constantly re-evaluated and displayed in STUK's emergency centre. The setup also serves a quality control purpose, because it constantly checks the availability of numerical weather prediction data from FMI.

The Laboratory consistently worked towards integrating RODOS and KETALE, and in 2010 the Laboratory succeeded in building a service interface to the RODOS software that can be used from the KETALE platform. Nowadays, KETALE users can request and visualise dispersion and dose assessments from RODOS in the same way as they would from other dispersion code.

Under the NKS projects Ecodoses and Pardnor, the ECOSYS model that is incorporated for ingestion dose modelling in the RODOS decision support system has been reviewed in the Laboratory of Environmental Research. The accuracy of food dose modelling has been improved through the gathering of available Nordic regional data. The focus has been on finding the appropriate parameters for different regions to be incorporated in the food chain and dose models. A large number of ECOSYS parameters have been examined, and improvements and targeting of these for Nordic conditions have been suggested (Hansen et al. 2010, Andersson et al. 2011). In addition, clean-up actions in the food industry in a radioactive contamination situation have been studied. Clean-up methods that can be used to decontaminate food industry facilities and their surroundings in a radioactive contamination situation are described in report STUK-A212, 2005.

EURANOS – European approach to nuclear and radiological emergency management and rehabilitation strategies

The Laboratory of Environmental Surveillance and Preparedness was actively involved in various EURANOS projects, as end-user involvement was recognised to be paramount for the development of the RODOS system. A Laboratory staff member was the deputy chairperson of the RODOS Users Group, which had an important role during the redesign of the RODOS software. The Laboratory also participated in many demonstration projects, which were used to generate crucial user feedback. The Laboratory made many contributions to the re-design of the RODOS system in the form of bug reports, feature requests and use case descriptions. For example, the Laboratory drafted the continuous mode use case (see above) and advocated the need for a service interface to RODOS. Apart from having been involved as users, the Laboratory provided programming expertise in the development of a forest model for RODOS.

Guidance on model adaptation driven by monitoring data

The objective of CAT2RTD12 (2006 – 2008) was to draw up guidance for modellers so that they could design models to use real measurement data more effectively for practical data assimilation purposes. The work included gathering certain basic information on existing DSS (and other consequence estimation models) and on measurement data available during different accident phases as well as studying possible factors affecting the interface between model predictions and monitoring data. Results were presented in the final work-package report and also published in a special issue of Radioprotection. The main conclusions were:

- Models must be specifically optimised to utilise the measurement data that are likely to be available to improve model’s results.
- Spatial and temporal resolutions of measurements are usually not the same as those used in the models. On one hand, the intensity of measurements should be increased when appropriate for the models and when possible in practice. On the other hand, models should be designed to use different (denser or coarser) internal spatial and temporal grids depending on the geographical locations (major population centres with many continuously operating measurement sites vs. rural environment) or on the calculated gradients of various quantities (dynamically determined grids) that are known to be measured.
- Certain measurements (such as airborne fallout mapping) produce huge amounts of data while others (e.g. nuclide-specific data from fixed air samplers) represent the situation at a number of distinct locations. Data assimilation procedures should be capable of managing both situations without increasing the overall uncertainty.

- The practical interface between measurements and models must be established before anything happens. For example, the locations of all existing important measuring sites should be incorporated in appropriate models in advance.
- Simple fast-running models should also be enabled for data assimilation, provided that the interface between the model output and monitoring data is suitable.
- In combining measurements and calculations one should also consider the overall uncertainty of the output and the way of expressing or displaying it.
- Modelling and radiation monitoring communities should have more co-operation and effective means for the mutual exchange of information.

EURANOS handbooks

The production of a generic handbook for the management of contaminated food production systems in Europe (EURANOS, CAT1RTD03), Production of a generic European handbook for the management of contaminated inhabited areas, including stakeholder opinion (EURANOS, CAT1RTD04) and the EURANOS demonstration projects (CAT1DEM1 and CAT1DEM2) were carried out in 2006–2009. In 2010 the Euranos Food Handbook was presented in an NKS seminar, which was arranged to gather Nordic stakeholders responsible for countermeasures against radioactive contamination of foodstuffs. During the seminar the adaptation of the Euranos Food Handbook to Nordic conditions was discussed.

Renewal of the monitoring network for the external dose rate

During 2005–2007 the monitoring network for the external dose rate was renewed. The renewed monitoring stations are based on studies conducted in 2004. The technical characteristics of the new monitoring stations were state-of-the-art and gave a new direction to the manufacturers. The renewed network is a real time network. For communication it uses the Virve network, which is dedicated for governmental use only. Monitoring results are sent automatically at 10-minute intervals to the USVA system.

In 2010, $LaBr_3$ spectrometers were installed in the existing external dose rate monitoring stations located around Finnish nuclear power plants. At the same time, automated data management and analysis software was developed to store and analyse spectra measured at these sites. This work was done in co-operation with Security Technology Laboratory. The outcome was a complete automated system from measurement to analysis of results and a user interface.

A monitoring station equipped with a $LaBr_3$ spectrometer is 20–50 times more sensitive than one equipped with GM tubes. A more important benefit is ability to identify the nuclide or nuclides that are responsible for an elevated dose rate. This identification is very important in planning counter measures when a radioactive release is detected.

6.6.6 Triage and monitoring of accident victims

TMT Handbook

In the aftermath of the Chernobyl accident, European national emergency response plans were focused on dealing with accidents at nuclear power plants. The perception of the increased threat has shifted the focus to also being prepared for the malevolent use of ionising radiation. In 2006–2009, the European Commission through the Euratom Sixth Framework Programme co-sponsored a specific targeted research project aimed at producing a practicable handbook for the effective and timely triage, monitoring and treatment of people exposed to radiation following a malevolent act. The handbook provides advice on how to prepare the response for such incidents and how to handle the situation both at the scene of the incident and at hospitals. Advice on public health interventions, including criteria for long-term follow up, are also described (TMT Handbook 2009).

CBRN threats and drinking water

Emergency preparedness authorities and security scientists have identified drinking water distribution networks as a conceivable target of a deliberate, malevolent attack. In any event, the disruption of water distribution associated with damage to network structures incurs discomfort and expenses. In the worst case, agents that are injurious to health could be used to contaminate water. The SecurEau project is addressing this issue by studying CBRN (chemical, biological, radiological and nuclear) agents. The main objective of SecurEau is to launch an appropriate response for rapidly restoring the use of the drinking water network after a deliberate contamination, specifically by i) designing methods for identifying potential contaminants, ii) modelling the distribution of the contaminants inside the network, iii) adapting and integrating various sensors in a surveillance system in an optimal configuration, and iv) developing methods for decontaminating polluted drinking water networks and installations, including the neutralisation of contaminated water and residues. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007–2011) under grant agreement no. 217976.

Biological dosimetry

Collaboration between the Swedish Defence Research Agency, Finnish Radiation and Nuclear Safety Authority and Norwegian Radiation Protection Authority (NRPA) has been established with the help of Nordic Nuclear Research funding to optimise a method for biological assessment of the radiation dose for specific application in emergency preparedness (BIODOS and BIOPEX). An assay in which chromatin is prematurely condensed (premature chromosome condensation, PCC) was investigated to determine the optimal assay conditions. PCC provides a potentially more rapid means of analysis as well as the ability to assess higher doses than the routinely applied dicentric assay. As a result, a dose calibration curve was established for the practical PCC ring assay and the assay was implemented by simulation of a mass casualty accident (Lindholm et al. 2010). The PCC assay was validated against the conventional dicentric assay. The study confirmed that the PCC ring assay is suitable for use as a biodosimeter after whole-body exposure to high doses of radiation. However, there are limitations to its use in the triage of people exposed to high, partial-body doses. As a continuation to the Nordic collaboration, experiments to broaden the dose estimation of exposure to neutrons for both PCC ring and dicentric chromosome techniques were performed together with the NRPA and Stockholm University (SU) (BIONCA). Dose calibration curves for both assays were established for neutron irradiations performed at the Petten reactor in the Netherlands. For the dicentric assay, excellent uniformity in dose calibration for data from both SU and STUK was observed. For PCC rings, the SU and STUK curves were not equally congruent, probably due to the less uniform scoring criteria. In addition, an exercise was conducted to simulate a criticality accident and to test the validity of the established dose calibration curves performing irradiations in Norway at the Kjeller reactor.

A multi-disciplinary collaborative project (MULTIBIODOSE) started in 2010 aiming to analyse a variety of biodosimetric tools and adapt them to different mass casualty scenarios. The following biodosimetric tools will be validated and established: the dicentric assay, the micronucleus assay, the gamma-H2AX assay, the skin speckle assay, the blood serum protein expression assay and EPR/OSL dosimetry of the components of pocket electronic devices. In the event of a large-scale radiological emergency, biological dosimetry is an essential tool that can provide a timely assessment of radiation exposure to the general population and enable the identification of those exposed people who should receive medical treatment. The biodosimetric tools must be adapted and tested for a large-scale emergency scenario. In biological dose assessment, appropriate software programmes are essential. Several laboratories have produced their own programs, but these are frequently not user-friendly and not available to outside users. The program called as CABAS consists of the main curve-fitting and dose estimating module and modules for calculating the dose in cases of partial body exposure, for estimating the minimum number of cells necessary to detect a given dose of radiation and for calculating the dose in the case of a protracted exposure (Deperas et al. 2007).

Both the IAEA and WHO have established international collaboration networks to enable a timely response in case of a large radiological event. Collaboration in these activities has been accomplished, for instance, through an international intercomparison of the dicentric assay (DiGiorgio et al. 2011). In addition, there is a newly established EURADOS working group for retrospective dosimetry that serves as a forum for discussion and co-operation on the various biological dosimetry assays (Ainsbury et al. 2010).

Investigations to assess the use of chromosomal translocations in retrospective biodosimetry have progressed. Data collected from 16 laboratories in North America, Europe and Asia on translocation frequencies measured in peripheral blood lymphocytes by fluorescence *in situ* hybridisation whole chromosome painting among 1933 individuals showed that age was strongly associated with translocations (Sigurdson et al. 2008). Ever smokers had significantly higher frequencies than non-smokers. Due to the large amount of data, a curvilinear relationship between translocation frequency and age was confirmed. The large study included an investigation conducted by European laboratories (Whitehouse et al. 2005) under the Euratom-funded concerted action (COD) and resulted in general guidelines for the use of translocations in retrospective dosimetry (Edwards et al. 2005). Further studies are ongoing to determine the long-term persistence of translocations in accident victims from the 1994 Estonian accident during 12 years following exposure.

TIARA – Treatment Initiative After Radiological Accidents

The TIARA project (Treatment Initiatives After Radiological Accidents) was part of the Preparatory Action on Security Research, launched by the European Commission in 2004 to reach preliminary conclusions on the needs for the security of EU citizens. The purpose of TIARA was to form a European network to participate in the health management of a crisis after the accidental or malevolent dispersal of radionuclides in the public environment. A main concern was to identify effective medical treatments for internal radioactive contamination and to state their benefits and limitations. A critical evaluation of current treatments for some nuclides of interest was made. The need to develop more effective treatment was recognised, also taking into account the ease of drug administration to a large number of persons. A relationship was established with an industrial manufacturer (Hameln Pharma Group, Germany) with the purpose of developing future cooperation between researchers and industry. The need for stockpiling of suitable and safe treatments for large scale distribution and the required amount was evaluated. TIARA partners took part in developing stockpiling recommendations for WHO. A booklet of practical guidance was produced on rapid, rough assessment of the internal dose for several nuclides (Menetrier et al. 2007a). The guide is intended to facilitate triage and treatment decisions. In a large-scale incident, this is of fundamental importance, as treatment may prove unwarranted for most of the affected. A training course was arranged to prepare and inform physicians about the management options for radioactively contaminated persons. Guidance was provided to medical responders who could potentially attend the incident site, reception areas and hospitals.

6.7 Dosimetry and metrology

6.7.1 Dosimetry for medical use of radiation

Calibration of plane parallel ionisation chambers in a ^{60}Co gamma beam for radiotherapy dosimetry

The aim was to determine the accuracy and reliability of the calibrations of plane parallel ionisation chambers, for the dose measurements in radiotherapy electron beams, when these calibrations are carried out in a ^{60}Co gamma beam. Since 1999 the plane parallel chambers have been calibrated in radiotherapy electron beams because of the differences between individual chambers within a given chamber type. However, the quality of the plane parallel chambers has improved in the last few years and the possibilities to return to the simpler calibration in a ^{60}Co gamma beam were investigated.

Plane parallel chambers were calibrated in accordance with the IAEA Code of Practice (TRS 398) for the absorbed dose to water in a water phantom both in a ^{60}Co gamma beam of the standard dosimetry laboratory of STUK and in radiotherapy electron beams (16–20 MeV). The water phantom for the calibration was reconstructed with the setting of the chamber at the required depth with a laser sensor. The results showed that for plane parallel chambers used in Finland the calibration can be reliably performed in a ^{60}Co gamma beam and the calibration practice can be changed. The change in the calibration method reduces calibration uncertainty and simplifies the calibration method.

The project was carried out in collaboration with radiotherapy departments and information on the method of calibration is distributed at annual meetings of radiotherapy physicists. The project ended in 2010 and the results were presented at the IAEA IDOS conference in 2010 (Jokelainen and Kosunen 2010).

Calibration and measurement techniques for dose-area product meters

The dose-area product (DAP) is generally measured to evaluate radiation exposure to patients in diagnostic X-ray examinations. To meet reasonable accuracy requirements in patient dose assessment, appropriate calibration methods for DAP meters are needed. For this purpose, the technical and dosimetric properties of DAP meters were studied, and a practical method of calibrating *field DAP meters* with a *reference DAP meter* was developed (Toroi et al. 2008a, Toroi 2009). This method was also introduced internationally (Pöyry et al. 2006a, 2006b, Toroi and Kosunen 2010), and based on our previous studies it was internationally recommended (IAEA TRS 457, 2007). In this method the reference DAP meter is calibrated comprehensively in a calibration laboratory also using other RQR radiation qualities than the standard ones. The field DAP meters are calibrated in their normal clinical environment, using radiation qualities that are typical in clinical practice. Because the response of a typical DAP meter depends significantly on the energy distribution of the X-ray beam, a single-valued calibration factor may not be adequate for the accuracy expectations in most cases (Toroi et al. 2008b, Toroi and Kosunen 2009). National guidance for users on the calibration of field instruments has been produced (Toroi et al. 2008c).

Calibration of an ionisation chamber for use in CT dosimetry

In the dosimetry of computed tomography equipment for X-ray diagnostics (CT scanners), the dose is determined in a long and narrow volume using a special ionisation chamber that measures the product of the dose and length. A Master's project was conducted to study various practical implementation models for calibrating such ionisation chambers and to determine the measurement uncertainties for these methods (Nieminen 2006). The work gave rise to a source document on calibration methods for CT dosimeters for use by the Radiation Metrology Laboratory at STUK. This pilot study has been extended with additional measurements during 2010 and 2011 and a scientific publication is under preparation.

Irradiation equipment for biological research

An irradiation device based on a 1 GBq ^{238}Pu source was developed. In the first stage (2005–2006), a broad-beam alpha-particle irradiator was constructed for cellular irradiation (Hakanen et al. 2006). In the second stage (2009–2010) the irradiator was updated to a narrow-beam mode of operation together with other technical improvements. The narrow beam device is capable of delivering an alpha-particle beam with dimensions 15 mm by 0.1 mm. Measurements using a semiconductor detector and solid-state nuclear track detectors together with Monte Carlo simulations were used to determine the dose distributions and microdosimetric parameters in the irradiated targets. The project was carried out in association with the Radiation Biology Laboratory (SBL) of the Department of Research and Environmental Surveillance (TKO) and forms part of research conducted by SBL into the bystander effect. The work was partly carried out as a part of the European NOTE integrated project (2006–2010).

Energy loss of protons in water

Interest in cancer therapy using either proton or heavy ion beams has significantly increased during the last decade with nearly 40 treatment centres operational at the moment and several tens being planned or under construction. Obviously, for successful treatments, knowledge of the dose absorbed by the tumour and the surrounding tissues is of paramount importance. A small change in the absorbed dose to the tumour could lead to a significant change in the probability of cure.

In radiotherapy, the dosimetry is often carried out relative to the ^{60}Co beam, in terms of the dose to water. The conversion from the dose to water in the ^{60}Co beam to that in the proton or heavy ion beam is usually carried out via the beam quality correction factor, which depends on the ratio of air and water stopping powers. This ratio is the main source of uncertainty in the proton or heavy ion beam calibration. The proton stopping powers are also needed to determine the dose distribution inside the patient. A small error in the stopping powers may result in a significant error in the dose, especially at the distal edge of the treatment region. The widely-used stopping power tabulations for water are based on refined Bethe's theory – no experimental data have been available above 2 MeV in proton energy. In this project we measured, for the first time, the stopping power of liquid water for protons at energies up to nearly 20 MeV.

In this work a new measurement system, applicable for liquid targets and heavy ion beams, was developed. During 2008 a prototype water target was designed and constructed, and the first tests were carried out using a proton beam at the Accelerator Laboratory of University of Jyväskylä. The test measurements were used to ensure that it was possible to construct a thin-layer liquid target and that the thickness of the target could be determined with sufficient accuracy. The final target was constructed during 2009 and proton measurements were carried out in early 2010 based on the experiences gained in the test measurements. The measured stopping power data agree, within experimental uncertainties, with the widely-used theoretical tabulations such as those given in ICRU report 49 or the tabulation by Janni.

Three presentations have been given at international conferences and the main publication from the experiment has been published in Physics in Medicine and Biology (Siiskonen et al. 2011). The journal raised the article in the Featured Article category to gain more visibility. *Medicalphysicsweb.org* released news concerning the experiment.

Weighting of secondary radiation in organ dose calculations

The current system of dose quantities in radiological protection is based, in addition to the absorbed dose, on the concepts of equivalent dose and effective dose. This system has been developed mainly with uniform whole-body exposures in mind. Conceptual and practical problems arise when the system is applied to more general exposure situations where the radiation quality is altered within the human body. In this work these problems are discussed, using proton beam radiotherapy as a specific example, and a proposition is made that dose equivalent quantities should be used instead of equivalent doses when organ doses are of interest (Siiskonen and Tapiovaara 2010). The calculations of out-of-field organ doses in proton therapy show that the International Commission on Radiological Protection-prescribed use of the proton weighting factor generally leads to an underestimation of the stochastic risks, while the use of neutron weighting factors as practised in the literature leads to a significant overestimation of these risks.

Accurate low-dose rate measurements using X-ray spectrometry

The suitability and accuracy of an HPGe detector for low-dose rate measurements was studied. The detector response for photons (1–300 keV) was modelled with EGSnrc and MCNPX Monte Carlo codes. For this purpose, a detailed model of the detector was constructed for the Monte Carlo codes and the sensitivity of the response was examined as a function of the level of detail in the response simulations. Software was developed to unfold the detector response, to compare the measured and unfolded spectra and to calculate the air kerma rates in the measured beam.

The conversion coefficients from the air kerma to ambient dose equivalent were determined for the standard radiation qualities used in the Radiation Metrology Laboratory of STUK (Hakanen et al. 2007b). In addition, the spectrally measured dose rate accurately matched the established dose rate of the Laboratory. The method allows accurate measurements of dose rates well below the background dose rate level.

6.7.2 Occupational dose monitoring

Monte Carlo simulations of occupational radiation doses in interventional radiology
Occupational radiation doses in interventional radiology can potentially be high. Therefore, reliable methods to assess the effective dose are needed. In this project the relationship between the reading of a personal dosimeter and the effective dose of a radiologist in interventional procedures of the head and heart were studied using Monte Carlo simulations (Siiskonen et al. 2007, 2008). In particular, the protection provided by a lead apron was investigated. Emphasis was placed on the sensitivity of the results to changes in irradiation conditions.

In the simulations a 0.35 mm thick lead apron and thyroid shield reduced the effective dose, on average, by a factor of 27 (the range of these data was 15–41). Without the thyroid shield the average reduction factor was 15 (range 6–22). The reduction sensitively depended on the projection and the X-ray tube voltage.

The dosimeter reading, when the dosimeter was worn above the apron and a thyroid shield was used, overestimated the effective dose on average by a factor of 130 (range 44–258) when the dosimeter was located on the breast closest to the primary X-ray beam. Without the thyroid shield the average overestimation was 69 (range 32–127). If the dosimeter was worn under the apron its reading generally underestimated the effective dose (on average by 20% with the thyroid shield).

This study indicates that even though large variations are present, the often-used conversion coefficient from the over-the-apron dosimeter reading to the effective dose, around 1/30, generally overestimates the effective dose by a factor of 2 or more.

Procedure-specific doses to the personnel in interventional radiology
The aim of this study was to determine occupational doses to the personnel in interventional radiology and cardiology, by distinguishing doses according to the procedures and according to the different steps of a given procedure (fluoroscopy/acquisition mode). Furthermore, the characteristics of personnel dosimeters were evaluated in particular for the measurement of small doses. The project was carried out in collaboration with Helsinki University Hospital, Kuopio University Hospital, the Central Hospital of Päijät-Häme and Savonia University of Applied Sciences, and with the companies Doseco Oy and Rados Technology Oy.

The characteristics of personnel dosimeters, including finger and wrist dosimeters, were investigated at the standard dosimetry laboratory of STUK. The doses to the personnel were measured for selected procedures at the participating hospitals. The results were compared between different procedures and with other X-ray examinations. The results were published in 2010 in the proceedings of the European IRPA and Radiology conferences.

The dosimetric methods proved to be feasible and the results of personnel dose estimations were taken into consideration in the development of the regulatory control of interventional radiology and cardiology. A summary of the project findings was published at the 2008 Radiation Safety Conference.

Double dosimetry procedures for the determination of the effective dose to the interventional radiology personnel

In high-dose interventional radiology (IR) procedures, for an accurate determination of effective dose to the personnel, measurements with two dosimeters have generally been recommended, one located above and one under the protective apron. Such “double dosimetry” practices and the algorithms used for the determination of effective dose were reviewed in this study, which was a joint EURADOS effort (Järvinen et al. 2008a, 2008b). Besides a literature review, a few most recently developed algorithms were tested in typical IR conditions. The effective dose and personnel dosimeter readings were obtained experimentally by using thermoluminescent dosimeters in and on a Rando-Alderson phantom provided with a lead apron. In addition, the effective dose and personnel dosimeter readings obtained by Monte Carlo calculations (Siiskonen et al. 2007, 2008b) for the same irradiation geometry were used to test the algorithms.

The results indicated there are neither harmonised regulations nor consistent practices for double dosimetry or for calculation of the effective dose to the personnel, and the effective dose estimations are not therefore fully comparable. A number of algorithms to calculate the effective dose have been developed, but there is no firm consensus on the most suitable algorithm. Most algorithms significantly overestimate effective dose, typically by a factor of 2–4, and some even more than by a factor of 10. In practice, calculation of the effective dose is mainly based on single dosimeter measurements, in which either the personal dose equivalent, directly (dosimeter below the apron), or a fraction of the personal dose equivalent (dosimeter above the apron) is taken as an assessment of effective dose. The studies suggest that there might not exist any double dosimetry algorithm that would be optimal for all interventional radiology procedures. It was concluded that whenever doses to personnel approach or exceed the dose limit, the IR conditions should be further investigated and the possibility of over- or under-estimation of the effective dose by the algorithm used should be considered, e.g. by comparing the calculation with a few other algorithms (Järvinen 2009).

Personnel doses in cardiological interventional radiography

The aim of the study has been to assess the radiation dose to personnel involved in heart X-ray assessments (cardioangiography assessments), as well as some cardiology procedures (such as PTCA and EF). In the study the dose has been defined for each assessment and procedure. Three different types of dosimeters have been used for dose assessments. Dose measurement protocols were also examined in laboratory conditions at STUK. The study was conducted by STUK in cooperation with two university hospitals and one procedural unit in a central hospital. Radiation doses were measured for approximately 350 different procedures. The dose for the doctor performing the procedure varied significantly depending on the length and difficulty of the operation: the average measured dose for the procedures at the upper arm level was about 50 μSv. The highest measured dose was 576 μSv. The average hand dose was about 150 μSv. The highest dose to the hand was 1 093 μSv, to the foot (ankle) 1 003 μSv, and to the head (forehead) 196 μSv. The doses for the procedure nurses were smaller because they are further from the primary beam during the procedures. The average dose to the nurses at the upper arm level during a PTCA procedure was 19 μSv, and the maximum dose was 199 μSv. The largest measured hand dose for a nurse was 492 μSv. According to the measurements, the effective dose to the doctor was about 1 μSv per procedure and the maximum dose was 12 μSv. Under normal working conditions the annual dose limits are not exceeded. However, it is possible to exceed the dose limits set for hands and feet. The average doses for patients in the procedures were below the reference levels.

The doses received by the personnel involved in the procedures can be quite high when compared to the annual dose limits. Thus, the appropriate use of radiation shields is necessary. Special attention should be paid to the optimisation of the use of radiation and procedural methodologies. The study utilised radiation meters suitable for monitoring personnel radiation exposure. Radiation meters with displays, or meters suitable for direct reading are good for observing working conditions, for day to day monitoring of doses and for training. The information obtained in the study could be used in hospitals to improve procedural and interventional methodologies and the planning of training. STUK could make use of the information in defining radiation protection guides and a graded approach to regulating radiation practices, as well as in determining the reference levels for patient doses.

Harmonisation and quality assurance in individual dose monitoring

STUK has participated in the research and development by the EURADOS working group “Harmonisation of individual monitoring in Europe and information on new techniques in this field”. The working group has been divided into four subgroups dealing with: (1) implementation of standards by dosimetric services; (2) harmonisation policies for the integration of dosimetry for internal and external occupational exposure; (3) electronic dosimeters for individual monitoring and other new developments; and (4) quality assurance, quality control and reliability of dosimetric systems. STUK has mainly contributed to the work on the implementation of standards by dosimetric services. The main outcome of these activities has been the EC technical recommendations for monitoring individuals occupationally exposed to external radiation (EC Report Radiation Protection No 160, 2009).

Occupational cosmic radiation exposure among cabin crew

Because of the lack of recorded flight history for cabin crew, a retrospective assessment of exposure to cosmic radiation is complicated. The aim in the study by Kojo et al. (2007) was to develop an assessment method for occupational exposure based on flight timetables. The frequency of flights, aircraft types and flight profiles were collected from timetables. The cosmic radiation dose was calculated with the EPCARD software. Based on annual doses and work history, the cumulative dose was estimated. The annual dose increased linearly over time: 0.7 mSv in 1960, 1.6 mSv in 1980, 2.3 mSv in 1985 and 2.1 mSv in 1995. The median cumulative dose was 20.8 mSv (minimum 0.4 mSv, maximum 61.6 mSv). This method provides a simple algorithm for occupational dose assessment for cabin crew and could also be used in other research settings.

6.7.3 Internal dosimetry

Changes in internal radiation doses affecting the population and special population groups receiving more ^{137}Cs from the diet than the population in general have been studied using whole-body measurements performed annually or at longer time intervals. The diet of the special population groups includes a lot of freshwater fish, wild mushrooms and wild berries from areas with high ^{137}Cs deposition. In reindeer herding areas, the diet includes reindeer meat as well as other produce from nature. In addition, a reference group representing people living in the Helsinki area has regularly been measured. Long-term follow-up studies are necessary in order to obtain representative dose estimates. The results also give information on sources from which Finns receive the highest radiation doses (Kurttio et al. 2010, Leppänen et al. 2011, Rahola in STUK-A217 (Ikäheimonen 2006), Rahola and Muikku 2005, Rahola et al. 2005). During the last six years the studies on two special diet groups have continued, using the mobile whole-body counter. The first group, from Central Finland, represents a population consuming forest berries and mushrooms and especially a lot of freshwater fish caught in small lakes in a region with high fallout. The mean body burden of the group was at the highest about 11 kBq in 1987, after the Chernobyl accident, but decreased to 1.9 kBq by 2009. Reindeer meat is the primary radiocaesium source for the second group, reindeer herders from northern Lapland. Although the mean deposition of radionuclides from Chernobyl fallout in Lapland was only about one tenth of that in southern Finland, the body burdens of caesium in Lapps are high because of the region's special food chain, lichen – reindeer – man. The body burdens of the male reindeer herders increased from 5.5 kBq to 13 kBq in 1988, but decreased to 1.7 kBq by 2005, when the last measurements of the group followed since 1961 were made. The body burdens of the female members of reindeer herding families, and the corresponding doses were about one third of the values for the male reindeer herders. For comparison, the mean ^{137}Cs body burden of the Helsinki reference group was about 0.2 kBq in 2010.

The STUK mobile whole-body counter was updated recently. The old mobile whole-body counter unit and the lorry were replaced. The project included equipping a new lorry with HPGe detectors and the necessary electronics and performing calibrations for whole-body counting. The acquisition of the lorry and the carossery as well as the installation of the interior and the frame of the measuring unit was performed in 2006. In 2007 the existing measurement setup with some modifications was installed and calibrated for temporary use in whole-body counting. In 2009 a prototype of the new measurement setup was built parallel to the present unit. The aim of improvements in the setup was to enhance the safety, ergonomics, and the detection efficiency for lung contamination. Based on the results, a completely new unit consisting of a background-shield chair and a detector stand was designed in 2009. The chair and detector stand will be installed in 2011. The result of the project, a new mobile measuring laboratory, will be used for performing whole-body counting for service, study and preparedness tasks.

The STUK-Voxel project was started with a literature survey to obtain information on the voxel phantoms used in different countries and suitable simulation programs for the purpose. In addition, a visit to IRSN, France, was made in order to become familiar with the use of phantoms, the necessary computer codes and numerical specifications of the detectors. As a first exercise, the existing mobile whole body counter was modelled, basically calculating the total gamma ray efficiency emitted by nuclei inside the human body. The Monte-Carlo simulation exercise “Intercomparison on Monte Carlo modelling of in vivo measurements of lung contamination with a Livermore phantom”, jointly organised by EURADOS Work Group 7 and 6, provided very useful learning process on more advanced modelling. The final results report will be published by the end of 2011, while the draft version already revealed that the results were in agreement with the measured ones. As a next step, mathematical modelling was used to guide the design of the new whole body counting geometries (see “The enhancement of the whole body counters” above). The preliminary results of these calculations and enhancement were presented at the NBC 2009 meeting (Huikari et al. 2009) and in the IRPA 2010 proceedings (Huikari et al. 2011).

Bioassays

Uranium concentrations in the household water, urine and hair of the occupationally unexposed Finnish working population were determined using inductively coupled plasma mass spectrometry (ICP-MS) in the **VIHURA** study conducted in 2005–2009. The age of the randomly selected participants ranged from 18 to 66 years. The mean concentrations of uranium in drinking water, urine and hair were 1.25 μg/l, 0.016 μg/l and 0.216 μg/g, respectively. The mean uranium concentration in the hair of the Finnish working population was from three- to fifteen-fold higher than the values reported in the literature, while the mean uranium concentration in urine was similar to those measured elsewhere in Europe. The observed large variation in the uranium concentrations in hair and urine can be explained by the variation in the uranium concentration in drinking water. Exceptionally high concentrations have been measured in private drilled wells in the granite areas of Southern Finland (Muikku et al. 2009).

In addition to uranium, the activity concentrations of ^{210}Pb and ^{210}Po in the urine of the special Finnish population groups have also been determined. In this study, people were divided into three groups mainly based on their diet. The first group comprised recreational fishermen, the second group consisted of reindeer herders, while people using drinking water with very high activity concentrations of ^{210}Po were selected for the third group. The fourth group was a control group. The results will be published in 2011. The study demonstrated the importance of possessing good knowledge of the background levels in order to be able to determine the additional exposure due, for example, to the malevolent use of radiation.

6.7.4 Activity measurements

In the national metrological programme for activity and activity concentrations, accurate, high quality and internationally comparable radiation measurements were attained. Versatility and real-time expert services were offered for national and international customers. Two international intercomparison exercises were participated in and two other validation studies were carried out. In addition, a rapid alpha spectrometric method, ^{14}C and ^{210}Pb methods and a calibration method for ^{222}Rn were examined more in detail.

Natural radioactivity

The standard ASTM method is the most commonly applied method for determining ^{222}Rn in drinking water. The method is calibrated with a ^{226}Ra standard solution that usually contains variable amounts of ^{210}Pb, ^{210}Bi and ^{210}Po if the standard has not recently been purified. Until now it has not been experimentally confirmed that these progenies do not interfere when the method is calibrated. In this study, interference was examined using three different organic cocktails and α/β liquid scintillation spectrometry to separately assess the effect of three radionuclides. The interference from ^{210}Po was 4% for one of the cocktails if the ^{226}Ra standard had been purified 5 years earlier. The interferences from ^{210}Pb and ^{210}Bi were negligible compared to that of ^{210}Po (Salonen 2010a).

Direct liquid scintillation (LS) methods are also widely used for surveying ^{222}Rn in drinking water. Two direct methods are used that differ in sample composition. In a two-phase sample, water lies below a water-immiscible cocktail, while in a homogeneous sample water is mixed with an emulsifying cocktail. Although these methods were developed in the late 1970s, their performances has not been simultaneously tested. Here, the methods were compared in two ways: by preparing both types of sample similarly from ^{222}Rn-bearing groundwater in one emulsifying and in three organic cocktails, and by calibrating the methods with a ^{226}Ra standard according to the irrespective procedures. The samples were measured using α/β LS spectrometry. The standard deviations of parallel samples and the repeatability of the measurements were excellent for both methods, except two-phase ^{226}Ra samples, whose efficiencies decreased slightly over time. This instability was due to interference from ^{210}Pb, ^{210}Bi and ^{210}Po, which accumulated in the ^{226}Ra standard, and possibly also to the migration of ^{214}Pb and ^{214}Bi into the aqueous phase and deficient transfer of ^{222}Rn from the water to the cocktail (Salonen 2009b, Salonen 2010b).

A simple method was developed to determine the activity concentration of ^{234}U and ^{238}U in water using alpha spectrometry. The method is based on rapid evaporation of water, mounting the residue in the vacuum chamber of an alpha spectrometer, alpha particle counting and subsequent spectrum analysis using a novel analysis program known as Adam. The method was compared to liquid scintillation spectrometry and alpha spectrometry with radiochemical sample processing. Consistent results were obtained.

The accuracy and repeatability of analysis method of ^{210}Pb from environmental samples was improved. The study focused on the storage conditions of the polonium-containing solutions, the tracer used in polonium analysis and the effect of storage time and acid concentration on ^{210}Po deposition. The intermediate precision and repeatability associated with the improved ^{210}Pb

analysis of fresh groundwater samples was 5% and 14%, respectively. These improved values were achieved by using glass bottles as storage containers for the solution remaining from the first ^{210}Po deposition, by rinsing the sample container with concentrated hydrochloric acid after storage and by using different isotopes of polonium as the yield determinant tracer in the first and the second deposition. Less polonium adsorption onto the storage container walls occurred with HCl than with HNO_3. The overall uncertainty in ^{210}Pb analysis was 11 ± 7% at the 95% confidence level. The minimum detectable activity concentration was 0.1 mBq l^{-1} calculated from blank samples and 0.05 mBq l^{-1} using the background counts of the alpha spectrometer (Vesterbacka and Ikäheimonen 2005).

A method for the measurement of radon emanation from soil samples with a liquid scintillation counter was developed in order to support radon mitigation. Slab-on-ground is a typical base floor construction type in Finland. The drainage layer between the slab and soil is a 200 – 600 mm thick layer of sand, gravel or crushed stone and thus may be a significant contributor to indoor air radon. Nonpolar organic solvents generally have high Ostwald coefficients. This enables absorption of gaseous radon directly into certain liquid scintillation cocktails. By utilising this property, a new method for measuring radon emanation from soil samples with a liquid scintillation counter was developed. The minimum detectable radon emanation rate is 0.01 Bq/(kg·d) (Turtiainen 2009b).

Carbon-14

^{14}C, or radiocarbon, is produced in nuclear reactors through neutron-induced reactions with carbon, nitrogen, and oxygen isotopes and is mostly released into the environment in gaseous releases such as carbon dioxide, $^{14}C0_2$. Nowadays, ^{14}C is one of the major contributors to the airborne radioactive releases in Finland. In recent years, ^{14}C measurements in the environment have become a part of the monitoring programme in the vicinities of Finnish nuclear power plants. The sample preparation for liquid scintillation counting (LSC) was carried out with a 307 Sample Oxidizer by PerkinElmer. The dried environmental samples were combusted completely in an oxygen atmosphere to carbon dioxide and water. The $^{14}C0_2$ was absorbed by the special reagent CarboSorb E (3-methoxypropylamine) and mixed with the LS cocktail PermaFluor E+. The samples were counted with a Quantulus 1220 low-level liquid scintillation counter. The effect of quenching was studied in order to optimise the measuring conditions for ^{14}C measurements with the sample oxidiser and the Quantulus liquid scintillation counter (Vartti 2009).

Intercomparisons in radionuclide analysis

Inter-laboratory comparisons of gamma-emitting nuclides in nuclear power plant coolant water have been carried out in Finland since 1994. The reactor water samples are taken and prepared by one of the two nuclear power plants and delivered to the participants. Since all the participants obtain their sample within just a few hours, it has been possible to analyse and compare the results for nuclides with half-lives shorter than one hour. All the main nuclides are regularly identified and the activities have been obtained with reasonable accuracy throughout the years. The overall deviation of the results has decreased over time. The effects of true coincidence summing and errors in the nuclear data used have been identified as potential sources of remaining discrepancies (Klemola 2008).

Another way of testing proficiency in the analysis of complex gamma-ray spectra is by participating in intercomparison exercises conducted using synthetically generated gamma-ray spectra. A synthesised spectrum constitutes a useful means of comparative analysis of complex spectra multilaterally without the impracticalities of using a sample drawn from a reactor (Dowdall et al. 2010).

The laboratory of Radionuclide Analytics has also participated in a comparison of the coincidence summing correction methods organised by the Gamma-ray Spectrometry Working Group of the International Committee for Radionuclide Metrology (ICRM). The first part of the comparison was restricted to point sources. The same experimental spectra, decay scheme and photon emission intensities were used by all the participants. The results were expressed as coincidence summing correction factors for several energies of ^{152}Eu and ^{134}Cs, and three source-to-detector distances (Lepy et al. 2010). Part two of the comparison was carried out in 2010 using extended sources.

The project GammaSem was conducted to provide a forum for discussion and the sharing of information on practical issues concerning gamma spectrometry and to establish a network of users of gamma spectrometry in the Nordic countries, thereby strengthening the collaboration and improving the competence of all participants in practical gamma spectrometry. The seminars have provided a welcomed starting point for broader Nordic collaboration (Strålberg et al. 2010).

The laboratory participated in the certification of a new reference material (CRM) for radionuclides in sea water from the Irish Sea (IAEA-443). Ten radionuclides (^{3}H, ^{40}K, ^{90}Sr, ^{137}Cs, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239+240}$Pu and ^{241}Am) were certified. The CRM can be used for quality assurance/quality control of the analysis of radionuclides in water samples, for the development and validation of analytical methods and for training purposes (Pham et al. 2011).

An intercomparison of the methodology (alpha, beta and gamma spectrometry) used for ^{238}U, ^{235}U and ^{210}Pb determination was carried out. The activity range of the 38 sediment samples varied from 10–700 Bq/kg for ^{210}Pb, 1–35 Bq/kg for ^{235}U and 10–800 Bq/kg for ^{238}U. Results obtained using the three methods were not statistically different at high activity levels, but agreement between the results decreased at lower sample activity levels. For ^{210}Pb, the smallest difference was found between alpha and gamma spectrometry. A good correlation between results from alpha and gamma spectrometry was observed over the whole activity range. In beta spectrometry, the results were slightly higher than those obtained by alpha or gamma spectrometry due to the impurity of ^{228}Ra. In ^{238}U analysis, good correspondence was observed between ^{238}U determined by gamma and alpha spectrometry, particularly at higher ^{238}U activity concentrations over 100 Bq/kg. In ^{235}U analysis, attention needs to be paid to interference from ^{226}Ra and its reduction (Vesterbacka et al. 2009).

An intercomparison exercise on ^{222}Rn determination in groundwater was organised between eight Nordic laboratories. The individual laboratory results were in most cases within 20% of the median value and within reported uncertainties. Considering the particular difficulties in preparing, transporting and analysing ^{222}Rn, being a gaseous radionuclide, the results indicate a high analytical capability among the Nordic laboratories (Vesterbacka et al. 2010).

Sampling and sample processing

For the validation of the method in radioactivity measurements, attention needs to be given to the validation procedure and the samples used in validation. The difference in extraction results between spiked water samples and groundwater samples demonstrates the importance of using real environmental samples in method validation. Relying only on spiked samples in method validation can lead to misinterpretations and incorrect results in analysis. The suitability of solvent extraction for ^{210}Po analysis from groundwater samples was assessed using three extractive scintillation cocktails, POLEX, TOPO and TNOA. Validation of the extraction method was carried out using both tracer-spiked samples and real groundwater samples. Extraction of polonium from spiked waters was successful and no coextraction of ^{234}U or ^{238}U occurred. However, the extraction results from groundwaters differed greatly from the spiked water samples. The main interfering nuclides were ^{234}U and ^{238}U, which led to incorrect results in ^{210}Po analysis. Due to the coextraction of uranium from real groundwaters, validation of the method was unfeasible (Jokelainen et al. 2010).

Sequential extraction was applied for isolated radioactive particles. Sequential extraction, i.e. the selective dissolution of soil components with increasingly aggressive chemical treatments, can be used to obtain information on the partitioning of radionuclides in soils and sediments, useful for predicting the mobility and bioavailability of radionuclides. An experiment was set up to test how feasible it is to carry out sequential extraction with isolated hot particles. Sequential extraction has commonly been used for sediments/soils, but the technique has never been applied on isolated hot particles before. Experiments proved that the technique was feasible with a single particle (Roos et al. 2010). The results demonstrated that only a small amount of both Am and Pu were easily soluble from the particle and that Am was slightly more soluble than Pu.

6.7.5 Irradiation facilities

Development of STUK's alpha-particle irradiation system

STUK's alpha particle irradiator was upgraded for narrow-beam irradiations (beam width of 0.1 mm). Three different types of narrow-beam collimator system were evaluated and Monte Carlo simulations for dose distributions behind the narrow beam collimator was performed. Based on the evaluation, a fixed-width, slit-like collimator made of tungsten alloy was deemed to be the best with regard to the ease of machining and dose distributions.

6.8 Non-ionising radiation

6.8.1 Electric and magnetic fields

Limiting exposure to magnetic fields near MRI scanners (MUST)

Occupational exposure to magnetic fields near magnetic resonance imaging (MRI) scanners was examined in the MUST project. A measurement system was developed to simultaneously measure gradient magnetic fields and fields generated by movement in a static magnetic field. The measurement system consisted of a 3D probe, a virtual oscilloscope and a computer. The system was calibrated with a Helmholtz coil setup for slowly varying magnetic fields (10–50 kHz). The suitability of the system for static magnetic field measurement was validated by tuning the Helmholtz coil setup for a static field and moving the 3D probe rapidly in and out of the field. The integrated static magnetic field was in good agreement with the known magnetic field inside the coils.

The magnetic field measurements were carried out for an open 1 T and a cylindrical 3 T MRI scanner. The magnetic fields significantly exceeded the reference levels given by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in positions where the medical personnel can have access during interventional procedures (Kännälä et al. 2009).

Restricting movement-induced electrical field

Movement in a strong static magnetic field in the vicinity of MR scanners induces electrical fields in the human body, which may result in various sensory perceptions such as vertigo, nausea, magnetic phosphenes and a metallic taste in the mouth. These sensory perceptions may be distracting if they were to affect the balance and eye-hand coordination of, for example, a physician carrying out a medical operation during MR scanning. The stimulation of peripheral nerve tissue by more intense induced electric field is also theoretically possible, but has not been reported to result from such movement.

The main objective of this study was to consider generic criteria for limiting motion-induced fields. In order to find a link between the static magnetic flux density and the time-varying induced electric field, the static magnetic field was converted to the homogeneous equivalent transient and sinusoidal magnetic fields exposing a stationary body. Two cases were considered: a human head moving in a non-uniform magnetic field and a head rotating in a homogeneous magnetic field. The electric field was then derived from the magnetic flux rate ($d\boldsymbol{B}/dt$) of the equivalent field by using computational dosimetric data published in the literature for various models of the human body. This conversion allowed the plotting of the threshold electric field as a function of frequency for vertigo, phosphenes and the stimulation of peripheral nerves.

The main conclusions of the study were: The basic restrictions for limiting exposure to extremely low frequency magnetic fields recommended by the ICNIRP in 1998 will prevent most cases of vertigo and other sensory perceptions that result from induced electric fields above 1 Hz, while limiting the static magnetic field below 2 T, as recently recommended by ICNIRP, provides sufficient protection below 1 Hz. People can experience vertigo when moving in static magnetic fields of between 2 and 8 T, but this may be controlled to some extent by slowing down head and/or body movement. In addition, limiting the static magnetic field to below 8 T provides good protection against peripheral nerve stimulation (Jokela and Saunders 2011).

Exposure to fields and currents from a plasma ball

Exposure to fields and currents from a plasma ball was examined in a study carried out by the Finnish Institute of Occupational Health and STUK. Plasma balls are captivating toys and they can be touched even by small children. Plasma balls generate high electric fields in their vicinity and high contact currents can occur when touching the balls. Therefore, it was considered important to measure the electric fields and the contact currents and compare the results with general public exposure limits. A typical plasma ball with a diameter of 20 cm was acquired from an internet shop. Measurements revealed that reference levels for general public exposure in the ICNIRP 1998 guidelines were clearly exceeded when touching the ball. The touching may not be harmful to health but causes a tingling sensation and even mild pain (Alanko et al. 2011).

Relation of induced current and SAR in the near field of RF dielectric heaters

An exposure assessment method based on the measurement of the current induced in the human body by the external electric field was developed for operators of RF dielectric heaters. Body current distributions were measured at 27 MHz using various current meters under a condition simulating the exposure to stray fields emitted by a dielectric heater. The specific absorption rates (SAR) and induced body currents were computed with finite-difference time-domain (FDTD) method using heterogeneous and homogeneous human models. The numerical analysis indicated that the basic restrictions for occupational exposure are not exceeded when the current induced in the limbs is lower than the action level (100 mA), even though the maximum electric field significantly exceeds the action value (61 V/m). For the heterogeneous human model, the exposure limit for local SAR was exceeded when the current induced in the ankle was 166 mA at a distance of 0.3 m from the electrode of the device. The vertical component of the current density proved to be more significant than the horizontal components, which were only important very near to the electrode. The computed results revealed no concentration of the induced current in the superficial tissues at 27 MHz. The results of this study were published as a Master's thesis and in Health Physics (Kännälä et al. 2008).

Numerical dosimetry for indoor distribution substations (MF Safety)

A dosimetric evaluation of worker's exposure to 50 Hz magnetic fields near a distribution substation was studied in this project. The source of the magnetic field was based on the low voltage switchgear of an actual transformer substation. The numerical computation was carried out with software based on the finite element method (FEM). A heterogeneous human model (adult male) was used in the computations.

The results of this study showed that the basic restriction given by the ICNIRP in 1998 for induced current density (10 mA/m^2 averaged over 1 cm^2 cross-sectional area in central nervous system) is not exceeded when the external magnetic field is equal to the reference n value (500 μT). The external field should be approximately double the reference value in order for the basic restriction to be exceeded. The main results of this study were published in a conference proceedings (Keikko et al. 2009).

Exposure systems and dosimetry for animal and human studies (HERMO)

Exposure systems and dosimetry were developed for three different biological studies on the effects of GSM mobile phone radiation. The effects on the central nervous system of young rats, on brain functions of anaesthetised domestic pigs and on skin cells of female volunteers were examined in these studies.

Rats

An exposure system for rats was previously developed for a cocarcinogenesis study carried out at the University of Kuopio. The system consisted of nine radial transmission line chambers with 24 rats in each chamber. Each rat could freely move in its own cage. After this study, part of the system (three chambers) was used in another study examining the possible effects of GSM mobile phone radiation on the central nervous system of young rats (CNS study). The rats were exposed to GSM mobile phone radiation (900 MHz, pulse duration 0.577 ms and pulse period 4.615 ms) for 2 hours per day on 5 days per week for their life time (cocarcinogenesis study) or until they were 8 weeks of age (CNS study). Two different whole-body SAR levels (low vs. high dose) were used. The whole-body SAR and its variation due to the movement of rats were determined by using FDTD computations with numerical models of young and adult rats. Computations carried out by VTT information technology were validated with rat phantom measurements made by STUK. The estimated whole-body SARs were 0.4 and 1.3 W/kg in the cocarcinogenesis study and 0.27 and 2.7 W/kg in the CNS study with an estimated uncertainty of 3 dB (K = 2). The instantaneous and lifetime variations in whole-body SAR due to the movement of the rats were estimated to be 2.3 and 1.3 dB (K = 1), respectively. The development of the exposure system and the RF dosimetry for these two studies are described by Puranen et al. (2009).

Pigs

The aim of this study was a dosimetric analysis of the setup used in the exposure of the heads of anaesthetised domestic pigs to GSM-modulated radio frequency electromagnetic fields (RF-EMF) at 900 MHz. The heads of pigs were irradiated with a half wave dipole using three different exposure routines: short bursts of 1–3 s at two different exposure levels and a continuous 10-min exposure. The electroencephalogram (EEG) was registered continuously during the exposures to search for RF-EMF induced changes. The dosimetry was based on simulations with the anatomical heterogeneous numerical model of the pig head. The simulation results were validated by experimental measurements with a custom-made homogeneous liquid phantom resembling the pig head. The SAR, defined as a maximum average over a 10 g tissue mass (SAR_{10g}), was 7.3 W/kg for the first set of short bursts and 31 W/kg for the second set of short bursts. The SAR_{10g} in the continuous 10-min exposure was 31 W/kg. The estimated uncertainty for the dosimetry was ±25% (K=2). The results were reported by Toivonen et al. (2008a).

Human volunteers

The aim of this study was a dosimetric analysis of an experimental setup used in the exposure of 10 female volunteers to GSM 900 radiation. The exposure was carried out by irradiating a small region of the right forearm of the volunteers for 1 h, after which biopsies were taken from the exposed skin for protein analysis. The source of irradiation was a half-wave dipole fed with a computer-controlled GSM phone. The SAR induced in the skin biopsy was assessed by computer simulations. The numerical model of the arm consisted of a muscle tissue simulating cylinder covered with thin skin (1 mm) and fat (3 mm) layers. The simulation models were validated by measurements with a homogeneous cylindrical liquid phantom developed for this purpose. The average SAR value in the biopsy was 1.3 W/kg and the estimated uncertainty ± 20% (K = 2). The main source of error was found to be variations in the distance of the forearm from the dipole (10 ± 1 mm). Other significant sources of uncertainty are individual variations of the fat layer and arm thickness, and the uncertainty of radio frequency (RF) power measurement. The results were reported by Toivonen et al. (2008b).

Exposure system and dosimetry for human volunteers exposed to GSM phone radiation (WIRECOM)

An exposure system and dosimetry were developed for three different experiments in which human subjects were exposed to GSM phone radiation. The experiments were carried out by the Finnish Institute of Occupational Health (FIOH) and Centre for Cognitive Neuroscience (CCS) at the University of Turku.

In the double-blinded experiment of the FIOH the human subjects were exposed to a SAR level higher than that from a typical mobile phone (SAR averaged over 10 g tissue mass was 4 W/kg). Identical phones were attached to each ear with a plastic holder and only the phone on the right side was transmitting. The experiment was carried out in a climatic room and the facial skin and ear canal temperatures were monitored. Near-infrared spectroscopy was used to measure the blood flow, oxygenation and de-oxygenation in the parietal and frontal area of the brain ipsilateral to the exposure.

CCS carried out two double-blinded experiments with a SAR level similar to a usual mobile phone (SAR_{10g} was 1 W/kg). In the first experiment an ^{18}F-deoxyglucose (FDG) tracer was injected into the subjects' blood circulation and they were exposed to GSM phone radiation while carrying out behavioural tasks. Identical phones were attached to each ear with a plastic holder and only the phone on the right side was transmitting. After the exposure the subjects' brains were scanned with positron emission tomography (PET) to evaluate the changes in brain glucose metabolism.

In the second study the subjects were exposed to GSM phone radiation and cerebral blood flow (CBF) was simultaneously monitored with a PET device. The power level was identical to the FDG experiment. Identical phones were attached to each ear and forehead with a plastic holder and each phone was transmitting at a time. ^{15}O water was used as a tracer and the subjects executed behavioural tasks during the experiment.

The transmitters of the GSM phones were deactivated, the batteries removed and antenna inputs replaced by a coaxial cable. The GSM signal was taken from an identical phone that was controlled by service software to continuously transmit a typical GSM voice-call signal. The signal consisted of 0.577 ms bursts of 902.4 MHz carrier frequency (GSM channel # 62) repeated every 4.615 ms. The power level was adjusted with an amplifier and signal was fed to the antenna of the exposing phone with a coaxial cable. The transmitted and reflected power levels were monitored during the exposures with an RF power meter.

SAR distributions were calculated for the three experiments with FDTD-based software. A CAD-based model of the mobile phone was used to make the numerical source model. A heterogeneous head model of an adult male was used in the calculations. The temperature probes and PET scanners were also modelled. The source model was validated by comparing the measured and simulated SAR values in a homogeneous head model (Specific Anthropomorphic Mannequin; SAM). The SAR values agreed well. Moreover, the simulated return losses and centre frequencies agreed well. The quality of the source model was therefore considered adequate.

Papers concerning the FDG-PET and CBF-PET experiments have been sent to scientific journals. The results from the FIOH experiment will also be reported in a scientific paper that is being prepared.

Specific Absorption Rate and Electric Field Measurements in the Near Field of Six Mobile Phone Base Station Antennas (EMSOFT)

The exposure to radio frequency electromagnetic fields was examined in close proximity (distances of 10, 100, 300, and 600 mm) to six base station antennas. The SAR in 800 mm × 500 mm × 200 mm box phantom as well as the unperturbed electric field (E) in air was measured. The results were used to determine whether the measurement of a local maximum of unperturbed electric field can be used as a compliance check for local exposure. In addition, the conservativeness of this assessment method compared to the ICNIRP basic restriction was studied. Moreover, the assessment of whole-body exposure by measurements was examined with the outcome of distance ranges in which the ICNIRP limit for local exposure could be exceeded before the limit for the whole-body SAR. The results showed that the electric field measurement alone can be used for an easy compliance check for local exposure at all distances and for all the antenna types studied. However, for some of the antennas, when the local peak value of E was equal to the ICNIRP reference level for unperturbed E, the exposure was very close to the basic restriction for localised SAR. It was also shown that the limit for the localised exposure could be exceeded before the limit for the whole-body averaged SAR only if the distance to the antenna was less than 240 mm. The results were reported by Toivonen et al. (2009).

Traceable measurement of field strength and SAR for the Physical Agents Directive (EMF and SAR)

Six national metrology institutes (five from Europe and one from Turkey) and STUK participated in this project, in which calibration methods were developed for field strength and SAR measurements for the frequency range from 100 kHz to 300 GHz. STUK and NPL (National Physical Laboratory, UK) developed different calibration systems for SAR probes below 400 MHz and for limb current meters in the frequency range from 10 to 110 MHz. No standardised method was known for the calibration of SAR probes below 400 MHz at the beginning of the project in 2008. NPL developed a vertically mounted large coaxial line short-circuited at the top and with the upper part of the centre conductor filled with tissue-simulating liquid. STUK developed a vertically mounted TEM transmission cell short-circuited at the top. The cell consisted of an air-filled lower part and an upper part partly filled with tissue-simulating liquid. The parts were separated with a quarter-wave transformer that provided good matching in the frequency range from 380 to 450 MHz. At lower frequencies, narrow-band matching was provided by inserting an LC (inductor-capacitor) circuit at the input of the cell. The SAR induced in the calibration points was determined by measuring the linear temperature rise in the tissue-simulating liquid during a few seconds with a high input RF power. SAR probes were calibrated at 30, 150 and 300 MHz in head simulating liquids made by NPL and at 380 and 450 MHz in a standard head-simulating liquid. The estimated uncertainty of the calibration was 8% for NPL's system and 13.5% for STUK's system. To validate the uncertainty budget, comparison calibrations will be carried out by NPL. The main results of the development of the SAR calibration system will be published in a scientific paper.

Limb current measurements were studied by developing calibration systems for limb current measuring devices. A coaxial 50 ohm line system and a rod antenna system in a large GTEM cell were developed by NPL and a calibration box with a centre conductor was developed by STUK. Results obtained from calibrations carried out with different systems were in good agreement. The deviations in the current were less than 5% up to 50 MHz and up to 10% up to 100 MHz. Ferrous-core current transformers are generally used in commercially available limb current meters. It is known that transformers of this kind may affect the current flowing in the conductor under measurement. Therefore, the effect of the transformer on the limb current was preliminarily studied at 50 MHz with simulations using a heterogeneous human model and below 50 MHz by measuring the ankle current of a human volunteer. Simulations and measurements showed no significant effect. In future work the effect will be examined more thoroughly and also at higher frequencies by using limb phantoms made by NPL. The main results will be published in a scientific paper.

RF metrology

The NIR laboratory participated in EURAMET project No. 819 (Comparison of Electrical Field Strength Measurements above 1 GHz), in which laboratories from nine European countries and South Africa measured the electrical field strength generated by the calibration systems of each laboratory in the frequency range from 1 to 2.5 GHz. A small dipole sensor was used as a transfer standard. The comparison indicated generally good agreement despite a number of measurement techniques being used (rectangular waveguide, TEM transmission cell, calibrated horn antenna in an anechoic chamber). However, the deviation of some results obtained, especially from anechoic chambers, exceeded the uncertainties estimated for the calibration method. STUK's results were in excellent agreement with the reference values. The deviations were clearly smaller than the estimated uncertainties. The main results were reported by Drazil (2011).

6.8.2 Optical radiation

UV radiometry

The NIR laboratory maintains good knowledge and skills in UV-radiation measurements. This has made it possible to participate in various scientific studies and comparison campaigns.

The uncertainty in the distance of the calibration lamp to the reference plane of the input diffuser is a significant error source in spectroradiometric calibrations. The position of the reference plane in Teflon diffusers was studied in the Metrology Research Institute at Helsinki University of Technology (TKK). With dome-shaped diffusers the offset was greatest. With diffusers of this kind in a typical calibration set-up, the measured 6 mm offset leads to 2.5% error (Manninen et al. 2006, Manninen et al. 2009). The diurnal variations in UV measurements (Meinander et al. 2006) and the albedo of snow (Meinander et al. 2008) were studied in co-operation with the Finnish Meteorological Institute. The NIR laboratory participated in two measurement comparisons. In a UVA meter comparison (Envall et al. 2006), all participating laboratories were within

5%. In the other intercomparison, erythemally weighted radiometers were compared (Hülsen et al. 2008). STUK's results showed slightly larger deviation from the others, but the results were still within the overall uncertainty of the calibration.

6.9 Nuclear safety

During recent years, STUK has not carried out its own research projects related to nuclear safety. Research on reactor safety and nuclear waste management are mainly carried out by the power companies TVO, Fortum and Posiva, VTT Technical Research Centre of Finland and technical universities in Helsinki and Lappeenranta.

6.10 International and national collaboration

In addition to actual research projects, a wide range of international and national co-operation research activities have been carried out. The objective of the co-operation is to enhance the impact of STUK research and expertise and to create and foster expert networks at national and international level, thus expanding the competence and knowledge pool available. STUK experts have participated in the activities of ICRP, ICNIRP, IRPA, WHO, IAEA and CTBTO. Preparation of strategic research agendas in the European and international level has been a major task during the recent years. European research platforms have been set up in low dose risk research (MELODI), radioecology (European Radioecology Alliance) and emergency preparedness (NERIS) during years 2009–2010. STUK participates in all of these and acts as coordinator of NERIS. STUK experts also had influential positions in ESARDA, European Safeguards Research and Development Association, eg. leading the working group on novel technologies. A major accomplishment was the organisation of the European IRPA Congress in Helsinki 2010, bringing more than 800 radiation protection professionals to Helsinki. In the national level, close contacts to stakeholder groups have been maintained to actively indentify their needs in terms of research. Enhanced research coordination due to reorganisation of the national research and innovation system has also featured the last five years period.

7 Research plans for the next five years

The two general objectives of research are to create new knowledge and to maintain and improve the competence of STUK as an expert body. Lines of research for the next five years are outlined in this chapter. A more detailed description of on-going (2008–2011) projects is provided in the report STUK-A249 (Salomaa and Sulonen 2011). STUK strategy will be updated during the years 2011–2012, which will have an impact on the project portfolio in the longer term.

7.1 Health effects of radiation

STUK will continue to work on the major issues of health risks of ionising and non-ionising radiation. The goal is to provide independent, influential, and science-based information for policy makers, authorities, society, and the media.

International research collaboration is of primary importance for strengthening the breadth of expertise, adopting new approaches and increasing statistical power in epidemiological studies. Collaboration is essential for efficient utilisation of the resources and in order to improve radiation safety in society. Overall risk assessment and control in environmental and occupational exposure situations will guide future research activities. Integration of low dose risk research at the European level will be a strategic aim. Prospects for integration of epidemiology and radiation biology will also be explored within STUK. STUK already has long experience in human biomonitoring and molecular epidemiological studies.

7.1.1 Epidemiology

The broad aims of the research are to determine the spectrum of health risks that are induced by exposure to low-doses of ionising and non-ionising radiation and to increase knowledge of the health risks associated with radiation in human populations. This research is mainly carried out by the Laboratory for Health Risks and Radon Safety.

Research topics are selected based on scientific and public health importance. Radiation risks, particularly those that are not well known (scientific relevance) or those that are of major concern to society (public health relevance), are assessed. Risk perception is among the criteria.

Research will be prioritised by following, for instance, the strategies of STUK and the ministries as well as research needs identified concerning the potential health effects of EMF by the EU Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), the research agenda for radiofrequency fields of the World Health Organization (WHO) and research agenda on ionising radiation of the Multidisciplinary European Low Dose Initiative (MELODI). At the national level, the newly formed SOTERKO consortium of three research institutes under the Ministry of Social Affairs and Health will set up a programme on risk assessment and management. Comparison of health risks from different sources and their prevention are among the research topics.

One of the strategic choices in research is utilising the opportunities for large-scale population-based studies provided by the highly developed Finnish registries such as Population and Cancer registries. Comprehensive national networks among scientists and the positive attitude of Finnish people towards participating in scientific studies are advantages for epidemiological studies and other studies involving humans.

The epidemiological research studies will include health effects associated with mobile phone use, the aetiology of brain tumours, the cancer risk attributable to the Chernobyl accident and cosmic radiation, and lens opacities among persons occupationally exposed to radiation.

The Laboratory will be involved in the European network of excellence on low dose radiation (DoReMi) activities, and potentially in future epidemiological research projects to be developed in the network. The epidemiological studies will be carried out in close collaboration with Tampere School of Health Sciences. The cost-effectiveness of the medical use of radiation and a bio-bank of samples drawn from radiation therapy patients are activities to be carried out in close collaboration with Turku University Hospital.

7.1.2 Biological effects of low-dose ionising radiation

In general, the research activities of the Laboratory of Radiation Biology will focus on key policy issues/areas identified by the 'High Level Expert Group on Low Dose Risk Research' (HLEG, *www.hleg.de*). The issues of the shape of the dose response for cancer, tissue sensitivity to cancer, individual variability, the effects of radiation quality and non-cancer effects are of particular interest. The research priorities of the laboratory during the next five years will be closely directed by the Transitional Research Agenda (TRA) created by DoReMi (Network of Excellence on Low Dose Research towards Multidisciplinary Integration). Furthermore, the guidelines provided by the Strategic Research Agenda (SRA) developed by MELODI (Multidisciplinary European Low Dose Initiative) will influence the long-term planning of research to be conducted.

DoReMi project

In the DoReMi programme (2010–2015), the Laboratory of Radiation Biology will mainly participate in work packages 5 (Shape of dose response), 6 (Individual sensitivities) and 7 (Non-cancer effects).

The laboratory is involved in the task 'Assessing the relative contribution of targeted (DNA), non-targeted and systemic processes to radiation carcinogenesis'. A small feasibility study to assess prospects for the establishment of a co-culturing system for 3D tissues will be carried out at STUK. The aim of this study is to test a new commercially available EpiAirWay 3D co-culture tissue model that consists of pseudostratified epithelium and subepithelial stroma (fibroblasts). This model provides an excellent tool to investigate intercellular communication and the micro-environmental contribution to non-targeted effects of radiation.

STUK scientists will continue to contribute in the survey of biomarkers for use in molecular epidemiological studies to be conducted for radiation exposed cohorts. Biomarkers of exposure, susceptibility and effect will be addressed. In addition, the available European cohorts on persons exposed to occupational, environmental and medical low dose radiation will be reviewed to identify the most suitable cohorts for use in future molecular epidemiological studies on individual susceptibility. Furthermore, the availability and quality of biological samples will be assessed for each cohort.

STUK is also participating in a feasibility study towards a systems biology approach to the radiation response of the endothelium, which aims at measurable and quantitative knowledge of the initial radiation response and the resultant biological cascades in endothelial cells. This goal is being addressed by using the HUVEC endothelial cell line exposed to low doses of ^{137}Cs gamma-rays for up to several weeks. At STUK, cytogenetic endpoints will be investigated.

EpiRadBio project

In the EpiRadBio project (2011–2014), the main aim of the study is to combine epidemiology and radiobiology to assess cancer risks in the breast, lung, thyroid and digestive tract after exposures to ionising radiation with total doses in the order of 100 mSv or below. STUK objectives are to investigate the role of the microenvironment and the intercellular communication in radiation-induced lung carcinogenesis. Epithelium-stroma interaction is being studied using *in vitro* models consisting of co-culture models (cell to cell, epithelial-fibroblast cells) and artificial human 3-D lung epithelium Epiairway models. In addition, identification of biomarkers following low-dose irradiation is one of our goals.

EPI-CT project

The laboratory is a partner in the EPI-CT project (2011–2016), in which the main aim is to conduct an international cohort study of paediatric CT patients in order to directly quantify health risks from CT doses, and communicate this information to stakeholders along with clear guidance on how this information may better inform CT dose optimisation in Europe. STUK is involved in the Biology work package in which the objectives are to test and validate biomarkers for potential use in large molecular epidemiology studies of CT-exposed individuals in the future. The purpose is also to evaluate the feasibility of using less invasive biological samples (e.g. saliva and urine instead of blood), and study the kinetics of DNA damage in order to select the optimal time to collect a representative sample in preparation for a more fully integrated epidemiological and biological study. The biomarkers to be investigated include assessment of DNA damage, mainly through monitoring of chromosomal aberrations, γ-H2AX foci, the measurement of oxidative stress, gene expression profiling as well as the measurement and/or profiling of cytokines. Outside the EU project, efforts to establish a Finnish cohort of CT patients will be conducted.

7.1.3 Biological effects of non-ionising radiation

Understanding the heath impact of electromagnetic fields (EMF) requires both epidemiological studies addressing the risk at the population level as well as consideration of plausible mechanisms that could lead to any adverse health effects. The WHO Research Agenda will be used in guiding the priorities.

Previous studies have detected changes in protein expression in human endothelial cells (EA.hy926) exposed to 900 MHz GSM radiation at SAR 2.4 W/kg. When the same cell line was exposed to 1800 MHz radiation at SAR 2.0 W/kg, either no changes have been observed or the changes have been very small. To address this discrepancy, a chamber comparison is being performed by simultaneously exposing the same batch of EA.hy926 cells at two similar exposure levels, 2 and 5 W/kg. Changes in protein expression in cells exposed in both chambers will be examined using 2DE-DIGE technology. Any proteins, that are shown to change their expression in response to irradiation will be identified with mass spectrometry and confirmed with Western blotting.

The issue of biological and health effects of mobile phone radiation remains unanswered, in large part due to inconsistency in the currently available scientific data. Research conducted in this laboratory has shown that mobile phone radiation might activate a cellular stress response in human endothelial cells and in this way affect the stability of the cytoskeleton. This, in turn, if occurring *in vivo* might have an impact on endothelial cell function as part of the blood-brain barrier. The studies, aiming at further elucidation of the impact of mobile phone radiation on the blood-brain barrier-related functions of endothelial cells, will be continued in the LIVE-IMAGING project. In this *in vitro* laboratory project the effects of exposure to mobile phone radiation on human endothelial cells will be examined during exposure by using a specially designed radiation exposure chamber and cells in which the cytoskeleton has been fluorescently labelled by transfection with green fluorescent protein (GFP). Changes in the cytoplasmic distribution of GFP will be followed during the exposure itself and during the post-exposure period using a confocal fluorescence microscope. Changes in the cytoplasmic distribution of GFP will be analysed by a computerised imaging system and software, and together with the observed changes in cell size and shape will provide information on the time course of the effect. Experiments will be performed at the Swinburne University of Technology, Hawthorn/Melbourne, Australia, where the specialised exposure equipment has been constructed and made available to researchers from SBL.

In 2008, we published the first, and so far the only, human volunteer study in which the effects of mobile phone radiation on protein expression in the skin were examined. The study, due to funding restrictions, was only a pilot one – executed using 10 human volunteers. The results should be confirmed using a larger group of volunteers.

7.2 Use of radiation

Research on the use of radiation will focus on the medical use of radiation and radiation safety issues in industry.

7.2.1 Medical use of radiation

In the medical use of radiation, the topics to be focused on are:

1. *The development of advanced dosimetric techniques* for the whole chain of dosimetry, i.e. from the calibration of instruments to measurements in clinical practice and evaluation of organ doses for radiation risk estimations.
2. *The implementation of justification and optimisation principles* in the high dose procedures of CT and interventional radiology and PET-CT.
3. *Justification, optimisation, patient doses and diagnostic reference levels* in paediatric CT and PET-CT.
4. *Improved estimation of the annual doses to the population from the medical use of radiation.*
5. *Verification of modern treatment techniques in radiotherapy and improved risk management.*

Development of advanced dosimetric techniques

This line of research will focus on the needs for computed tomography (including modern applications), interventional radiology and nuclear medicine, to cope with the recent development of the X-ray equipment, imaging technologies and nuclear medicine treatments. These studies (except for nuclear medicine) will be mainly be related to an IAEA-coordinated research project during 2010–2013. Part of the activities will also be undertaken in collaboration with the relevant working groups of EURADOS, in particular the calibration of KAP meters and the studies on CT dosimetry. Some of the studies are STUK's own research activities.

The aim of the IAEA CRP is to evaluate the feasibility and accuracy of the methods described in the IAEA publication "Dosimetry in Diagnostic Radiology: An International Code of Practice" (IAEA TRS 457). This concerns both the calibration of dosimeters and clinical dosimetry. The research group includes experts from calibration laboratories and hospitals from several countries. The usefulness of the described methods for challenging and new dosimetric situations is being reviewed, tested and evaluated.

These studies are joint efforts between the Radiation Metrology Laboratory of STUK (SSDL), the other sections of the Department of Radiation Practises Regulation (for some parts of the studies), and Finnish university hospitals. The whole dosimetric chain from the calibration of dosimeters to the determination of organ doses will be assessed and improved calibration and measurement methods will be developed. Calibration techniques are to be investigated at the Radiation Metrology Laboratory, and the clinical dosimetry methods are to be investigated at hospitals. Methods for the calibration of dosimeters for X-ray imaging methods will be improved to better cover the challenging dosimetric situations. The proposed project will help in implementing methods for advanced dosimetry measurements in hospitals.

Implementation of justification and optimisation principles

This activity includes studies on indication-based approaches, the justification of examinations against referral criteria and the implementation and revision of the (diagnostic) reference levels. These studies are mainly the research activities of the Department of Radiation Practises Regulation for the direct support of the regulatory functions, i.e. review and control of the implementation of justification and optimisation and for the setting of diagnostic reference levels. These studies are mainly being carried out in collaboration with medical users of radiation, and part of the work will be a joint effort by a special cooperation programme between a few other relevant health care authorities.

Justification, optimisation, patient doses and diagnostic reference levels in paediatric CT and PET-CT

The first aim is to study the implementation of the justification and optimisation principles in paediatric CT and PET-CT examinations, by reviewing and comparing the indications and protocols for paediatric examinations. PET-CT is included because it is anticipated that these examinations are not well optimised, as paediatric radiologists are not usually involved. Furthermore, children having a PET-CT are often subjected to several other examinations, which highlights the importance of proper optimisation. The second aim is to collect patient dose data in order to assess the feasibility of setting diagnostic reference levels for paediatric patients. These studies are being carried out in collaboration with Finnish university hospitals and a few hospitals in the other Nordic countries and the Baltic countries.

Improved estimation of the annual doses to the population from the medical use of radiation

The aim is to improve the accuracy of estimations of the dose to the population caused by the medical use of radiation, both in X-ray diagnostics and in nuclear medicine. Furthermore, the feasibility of the methods recommended by the European Commission (EC Report: Radiation Protection 154) will be examined in order to develop the application and consistency of the methods for population dose estimation in Europe. These studies are mainly related to the EC-funded project entitled “Study on European Population Doses from Medical Exposure” (Dose Datamed 2), for 2010–2012.

Verification of modern treatment techniques in radiotherapy and improved risk management

Verification of modern treatment techniques will mainly be carried out in the context of the EMRP research programme (see Dosimetry and metrology below). The improvement of risk management is being addressed by developing an improved learning system for incidents and accidents in collaboration with other relevant bodies.

7.2.2 Radiation safety in industry

STUK is participating in the EMRP project MetroMetal, which aims to develop ionising radiation detection techniques for the steel industry using scrap metals. The orphan sources in scrap loads pose a radiation safety problem in the steel mill and may result in the contamination of steel products. Measurement techniques will be developed for the early detection of such sources and, on the other hand, to quantify the activity concentration of the end product. STUK is also participating in an EMRP call for a project that will consider the security of radioactive material by using coupled neutron and gamma radiography and spectrometry. The metals industry has in recent years become aware of the risks posed by orphan sources and radioactive materials entering the recycling chain. The research will endeavour to provide guidance in preparing radiation emergency operating procedures in the metals industry and a report on the methods employed at Rautaruukki Steel Mill in Raahe.

Current regulatory requirements regarding waste and releases arising from the use of unsealed radioactive sources are based on assessments made some decades ago. Since then the uses have changed and the possible exposure pathways may also have changed. Research on the current uses of unsealed sources, possible exposure pathways and on realistic estimates of public exposures is needed.

Several new accelerators for isotope production and research activities have recently been taken into use. This has increased the need to evaluate whether there is a need to establish practice-specific regulations or guidance. Research on the safety and safe use of accelerators is needed to support this decision making and the possible establishment of practice-specific regulations or guidance.

7.3 Occurrence and mitigation of natural radiation

Research on the occurrence and mitigation of natural radiation will be carried out by several laboratories.

7.3.1 Radon in indoor air

The main goal of the radon research is to reduce human exposure to indoor radon. Therefore, indoor radon prevention in new construction, mitigation in existing dwellings and the development of guides is the main aim of the research. The Laboratory of Health Risks and Radon Safety also aims at building a comprehensive overview of the occurrence and factors affecting indoor radon concentrations in homes and in work environments in Finland.

The database containing radon concentrations measured in the Laboratory and other data of the apartment or the workplace is an invaluable tool in research and communication with the public. STUK will maintain nationwide and regional maps and statistical summaries concerning indoor radon that show, for instance, areas where the most active mitigation measures should be taken, or time trends of radon concentrations.

Radon causes the main radiation dose in Finland on average, and the Laboratory will therefore continue providing information for decision makers involved in regulatory work: STUK Radiation Practices Regulation, the Ministry of Social Affairs and Health, Ministry of the Environment, and municipal authorities.

Information on the occurrence of radon, as well as radon prevention and mitigation methods, is also provided directly to the general public, especially to house builders and owners.

7.3.2 Radon in drinking water

The exposure of the public to naturally occurring radionuclides in drinking water supplies remains an issue, as drilled wells are increasingly popular sources of household water in sparsely populated areas. EU Member States are now also requested to report water quality data to the Commission from small supplies (50–5000 users). Data on radioactivity concerning these water works is mainly over 20 years old and should be updated, preferably in cooperation with Valvira (National Supervisory Authority for Welfare and Health) and GTK (the Geological Survey of Finland). Outcomes of studies on household radon removal units and the impact of water treatment techniques on doses to the public will be summarised in a doctoral thesis.

7.4 Environmental research

7.4.1 Radioecology

With a renewed interest in nuclear energy and the scientific challenges related to the nuclear fuel cycle, the need for radioecological expertise is increasing worldwide. Concurrently, education related to radioecology has steadily declined, leading experts are approaching retirement, and funding for radioecological research is at a minimum in many European countries. To face this challenge and avoid further fragmentation, nine leading organisations have established a Network of Excellence in radioecology, called STAR (Strategy for Allied Radioecology). The goal is to efficiently integrate important organisations, infrastructures and research efforts into a sustainable network that contributes to a European Research Area in radioecology under a joint Strategic Research Agenda. To achieve this, a Joint Programme of Activities will be implemented covering the integration and sharing of infrastructures; training, education and mobility; knowledge management and dissemination; as well as three key research themes (integrating human and non-human radiological risk assessments; radiation protection in a multi-contaminant context; ecologically relevant low-dose effects). A vital role of STAR is to develop a transition plan to sustainability that invokes a permanent management structure (the European

Radioecology Alliance) and long-term funding for radioecological research, infrastructure, training and education.

Nordic co-operation in the investigation of food chains will continue. The NKS-funded project Radpast was started in 2010, in which radionuclide transfer in the food chain soil – pasture – cow's milk being assessed in all Nordic countries. Sampling is covering clay, sandy and humus soils. The focus is on natural radionuclides, but ^{137}Cs and ^{90}Sr are also being determined.

The research programme for radioecology of forest management will continue in collaboration with the Finnish Forest Research Institute. Testing of the management effect on forests will be focused on complementing the knowledge base on factors influencing the remedial effect of various forest management methods and the related time dependencies. The results will be published in scientific journals.

Radioactivity in the Baltic Sea will be monitored and assessed in co-operation with the Helcom-MORS group. More attention will be paid to the natural radionuclides such and ^{210}Po and uranium isotopes.

In freshwater environments the long-term behaviour of ^{137}Cs will be further investigated. The ^{137}Cs concentration in water and fish will be determined in selected lakes where water chemistry data are also available to investigate the relationship between lake environmental factors and the uptake of ^{137}Cs by fish.

In the Regional Laboratory of Northern Finland, the main emphasis will be moved from radiation monitoring to environmental research during the next five years. New research areas will include environmental impact studies on mining sites and the environmental aspects of the planned new nuclear power plant in Northern Finland.

In the Arctic Monitoring and Assessment Programme (AMAP), preparedness for potential future contamination of the Arctic as a result of accidents involving nuclear and or radioactive materials is an issue of particular concern. The development of assessment approaches that will support risk reduction, prevention strategies and improved emergency preparedness is therefore identified as an issue of high priority for the next phase of AMAP work on radioactivity in the Arctic. The potential impact of climate change on the transport of radionuclides to the Arctic from sources outside the region, and the way in which the distribution of radionuclides already present in the Arctic may be influenced by a change in climate, are of particular interest. The laboratory is utilising airborne radioactivity monitoring data on two cosmogenic isotopes (^{7}Be and ^{22}Na) to study how atmospheric transport processes are affected by large-scale climatic phenomena, e.g. the North Atlantic Oscillation, Arctic Oscillation and Southern Oscillation. The results could be used in improving atmospheric modelling and in climate change studies. Climate change is one of the great challenges identified by the Government of Finland.

7.4.2 Foodstuffs

The Laboratory of Environmental Research will continue to gather basic information on the activity concentrations of both naturally occurring and artificial radionuclides in different Finnish foodstuffs. Challenges posed by the expanding mining industry are shifting the focus towards naturally occurring radionuclides.

The laboratory will continue to provide information on the variation in ^{137}Cs concentrations in wild foodstuffs (mushrooms, berries, game meat and freshwater fish) in Finland. Changes in ^{137}Cs levels in the course of time and variation between different areas are being studied, as well as variation in internal radiation doses due to the consumption of wild food in different areas. The results provide information for assessing the situation in Finland regarding to the maximum permitted level, 600 Bq/kg, recommended to be respected when placing wild game, wild berries, wild mushrooms and lake fish on the market (Commission recommendation 2003/274/Euratom).

7.4.3 Radiation protection of biota

STUK will participate in the IAEA Programme on Environmental Modelling for Radiation Safety (IAEA, EMRAS).

Estimation of doses to biota will be carried out for the Baltic Sea (i.e. for the Gulf of Finland and the Bothnian Sea). In addition, doses will be estimated for the surroundings of planned mines. For both studies the ERICA Tool will be applied, using existing data produced by monitoring programmes or radiological baseline studies.

7.4.4 Mining activities

Talvivaara mining company has recently planned to recover uranium as a by-product from the metal extraction process. In the Savukoski municipality there is a plan to open a phosphate mine at Sokli. In addition, many uranium prospecting projects have been launched in Northern Finland. The Laboratory of Northern Finland has carried out a radiological baseline study at the site of Sokli, and a baseline study of the Talvivaara mine started in 2010. These baseline studies will also be used for research purposes. In addition, the laboratory is participating in a project investigating the mobilisation of radionuclides and heavy metals from mining mill tailings. The project is funded by the Finnish Academy and coordinated at the University of Helsinki, Laboratory of Radiochemistry. The main objective of the project is to study the solubility of natural radionuclides from uranium mill tailings waste and the chemical forms of dissolved radionuclides to evaluate their transfer properties in the surrounding soil. Secondary targets are mill tailings waste from apatite mining and the solubility of heavy metals. The studied sites are Sokli, Talvivaara and the former Paukkajanvaara uranium mine in Eno.

7.5 Preparedness for nuclear and radiological threats and emergencies

The research and technological development on preparedness for nuclear and radiological threats and accidents will focus on novel technologies for nuclear security and radiation protection, decision support systems and biological dosimetry.

7.5.1 Novel Technologies (NT)

A four-year project is planned based on the results from non-destructive analysis. The main research themes of this NT project will be:

- novel radiation detection and analysis concepts such as coincidence spectrometry with alpha particles and conversion electrons
- complementary particle analysis techniques such as nanotomography
- non-destructive analysis of exotic samples such as air samples collected in the 1950s and 1960s in Finland (nuclear weapons tests in the atmosphere) and
- the development of electrostatic samplers.

The development of an electrostatic sampler is important for unmanned aerial vehicles, since no pumps or filters would be needed. Massless sampling with electrostatic samplers would also pave the way for high resolution *in situ* alpha spectrometry.

The NT project will also concentrate on state-of-the-art fast digital nuclear electronics. Time-stamped event mode data collection will first be studied in laboratory conditions using a multi-detector setup. This work will also require the development of new software. Later on, the technique will be expanded to in-field applications. This development will also have an effect on the technologies that are currently been developed in remote monitoring of alpha emitters and the detection and identification of neutron emitters.

The continuation of work related to the rapid identification of alpha emitters will be technical in nature, since the goal is to develop a miniaturised prototype of the alpha spectrometer operating in ambient air pressure. The spectrometer is intended to be developed under the EU-FP7 research programme. Its data collection, storage, distribution and analysis software will be based on existing software components such as VASIKKA, LINSSI, LIBS, SNITCH and ADAM.

In the future, the main research effort in experimental nuclear physics will be devoted to studies on neutron-induced fission yields. These yields for ^{131m}Xe, ^{133m}Xe, ^{133}Xe and ^{135}Xe as a function target (^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu) and incoming neutron energy are desired, for example, by the CTBTO. Another research goal along this line is to study in detail the decay properties of nuclides such as ^{241}Am, ^{239}Pu, ^{240}Pu, ^{235}U and ^{238}U. In particular, their conversion electron yields possess significant uncertainties. Accurate decay data for these nuclides are also very important for the NT project. Note that ultra-pure samples of these nuclides can be prepared, if needed, at the University of Jyväskylä.

Technology and software integration is continuing according to the demand of society for safety, security and safeguards. In practice, this means the development of prototypes to more mature levels. In this process, the contribution of the private sector is of crucial importance. These integration projects also enhance the flow of know-how, software and hardware from the laboratory to in-field measurements, and vice versa. From the emergency preparedness perspective, these activities also have several benefits. The extensive use of in-field software such as VASIKKA in everyday research will help to develop and debug the program, making it more reliable. In addition, the use of in-field tools in routine work will significantly impact on our capabilities to operate in the field.

In conclusion, the Laboratory of Security Technology is continuing its research to support emergency preparedness, environmental monitoring, nuclear security and safeguards. The Laboratory has very high-level know-how on spectroscopic measurements and related analyses for in-field and laboratory applications. This know-how will be tailored for the needs of society. More specifically, by further developing the reach-back capabilities, analysis services can also be offered to other authorities and departments and laboratories of STUK. Specific projects will be carefully planned according to the strategy of STUK, which will be renewed in 2012. In any case, strengthening of the co-operation between universities, the EU, IAEA and sister organisations in different countries will be of major importance.

7.5.2 Decision support systems

In the coming years, STUK will actively participate in the following research projects:

- NERIS-TP, Towards a self sustaining European Technology Platform (NERIS-TP) on Preparedness for Nuclear and Radiological Emergency Response and Recovery, Euratom FP7, 2010–2013,

- DETECT, Design of optimised systems for monitoring of radiation and radioactivity in case of a nuclear or radiological emergency in Europe, Euratom FP7, 2010–2013
- SecurEau (Security and decontamination of drinking water distribution systems following a deliberate contamination) will continue until January 2013.
- CEEPRA, Collaboration Network on EuroArctic Environmental Radiation Protection and Research, EU Kolarctic ENPI, 2011–2013

STUK is engaged in European networking activities in the areas of emergency management. Deputy Director Raimo Mustonen is the president of the European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery (NERIS Platform), aiming to create a self-sustaining association for the development of a joint European approach in responding to and recovering from nuclear and radiological emergencies. The vision of the NERIS Platform is that by 2015 the self-sustainable platform will exist, and by 2020 all European organisations that are members of the association will be using compatible technology and methods for consequence management of emergencies. At present the Platform is writing the Strategic Research Agenda (SRA) for the coming years.

The Laboratory of Environmental Surveillance has no plans for specific research for the next five years. The Laboratory is focusing on emergency preparedness projects and on the continuous technical development of information systems which it is responsible for using and maintaining. Another continuous focus is carrying out the environmental monitoring programme. Technological development is focused on the following areas:

1. Development of the radiation monitoring of the environment. In an emergency, automatic monitoring networks (accompanied by manual measurements) combined with state-of-the-art data management systems provide a rapid and reliable overview of the radiation situation and thus facilitate better informed decision making.
2. Development of the tools and information systems for gamma spectrometric analysis.
3. Maintenance of tools for the KETALE system and its further development in order to merge the functional areas of more traditional decision support systems with the collaborative feature set of content management systems into a usable, reliable, secure and extensible platform that fits into our actual emergency management process as neatly as possible .
4. Development of the tools, methods and procedures for emergency situations.

5. Analyses of accidents and threat scenarios. Results of various threat studies provide background information and support material that can be used in emergency planning and in real situations.

STUK will continue to carry out research on countermeasures and the development of restoration management for agricultural land, foodstuffs, water supply networks and forests. Finland received 4% of the Chernobyl release, and excess levels of ^{137}Cs can still be found in natural produce in some areas of Finland. This experience provides an excellent basis for assessment of the consequences of the accident in Fukushima. Fukushima will no doubt impact on research in the coming years and revitalise studies on the scenarios, consequences and management of severe accidents. The lessons learnt will be considered in revisions of internal emergency preparedness guides.

The Regional Laboratory of Northern Finland is coordinating an international three-year EU project (CEEPRA) that is strengthening cross-border cooperation between the key authorities, research organisations and stakeholders in the Arctic regions of Finland, Russia and Norway. The aim of the project is also to improve emergency preparedness and capabilities and perform risk assessments in the case of nuclear accidents in the region.

7.5.3 Biological dosimetry

The investigation of a variety of biodosimetric tools and their adaptation to different mass casualty scenarios will be performed as part of the multi-disciplinary collaborative MULTIBIODOSE project (2010–2013). The tools (dicentric assay, micronucleus assay, γ-H2AX assay, the skin speckle assay, the blood serum protein expression assay and EPR/OSL dosimetry in components of pocket electronic devises) will be validated and established: the assays complement each other with respect to sensitivity, specificity to radiation and the exposure scenario as well as the speed of performance. The project will involve the key European players with extensive experience in biological dosimetry. Training will be carried out and automation and commercialisation pursued. An operational guide will be developed and disseminated among emergency preparedness and radiation protection organisations. The Radiation Biology laboratory is also participating in a Euratom proposal for the establishment of a sustainable network in biological dosimetry that will involve a large number of experienced laboratories throughout the EU (RENEB). The network would significantly improve the accident and emergency response capabilities in case of a large-scale radiological emergency.

7.6 Dosimetry and metrology

In the coming years, topics to be addressed in dosimetry and metrology include methods and dosimetric data for novel radiotherapy techniques, metrological traceability for dosimetry in nuclear medicine, quantities, calibration and measurement techniques for dosimetry of diagnostic radiology, occupational dose monitoring, dosimetry for radiobiological investigations and internal dosimetry.

7.6.1 Dosimetry and metrology

Methods and dosimetric data for novel radiotherapy techniques

New radiotherapy modalities, such as arch beam external photon therapy and modulated electron beam therapy, are already used in Finland, while external proton beam therapy may also be introduced and research will be necessary, at least in order to obtain the required expertise. The development of dosimetry methods for small, dynamic and intensity modulated irradiation fields will be a focus in this area. These studies will be part of the European Metrology Research Programme (EMRP). Stopping power measurements of liquid water for protons and heavy ions will be considered to improve the accuracy of dosimetry in hadron beam radiotherapy.

Because STUK is the National Metrology Laboratory for ionising radiation in Finland, the European Metrology Research Programme is available to STUK and offers an excellent opportunity for shared cost actions in the field of dosimetry and metrology. The EMRP includes several research areas that consider the metrology of ionising radiation and are relevant to the activities of STUK, including calibration techniques in the laboratory as well as the techniques and methods in applied dosimetry, which will be included in the scope of activities. STUK has participated in the Health I call in two projects for metrology of radiotherapy and has prepared for the Health II call by introducing potential research topics for the development of verification techniques for the dosimetry of external radiation therapy using photon and electron beams.

Metrological traceability for dosimetry in nuclear medicine

Dosimetry in nuclear medicine will be reviewed and effort needs to be focused on areas that are important for developing a more reliable dosimetry chain to be used in Finland. In particular, the radionuclide-specific calibration of well-type ionisation chambers at hospitals and the metrological traceability of dose quantities (not only of activity) needs to be investigated.

Quantities, calibration and measurement techniques for dosimetry of diagnostic radiology

In diagnostic radiology, the dosimetry for computed tomography has been challenged by the introduction of wide-beam scanners (both multi-detector row and cone beam CT). STUK is interested in participating in the discussions and development of novel measurement methods and calibration techniques for the required dosimeters. Calibration procedures for dose-area product meters and dose-length product meters will be developed and put into practice. Nordic Recommendations for calibrating KAP meters have been planned to be prepared in the Nordic group for dosimetry.

An important forum of these discussions is sub-committee 62B of the International Electrotechnical Commission (IEC), in which equipment standards are being developed. In this work the IAEA/WHO secondary standards dosimetry laboratory network and the EURADOS working groups also offer a natural and good environment for collaboration. Close collaboration with the University of Helsinki will continue in research and doctoral training in the field of medical physics and dosimetry.

Dosimetry for radiobiological investigations

The radiobiological investigations on the health detriment caused by ionising radiation will be one of the key research areas of STUK. The main contribution to these research projects comes from the department of Research and Environmental Surveillance (TKO). The necessary support for research and development in dosimetry for cell culture and tissue irradiations will be provided, along with the development of irradiation devices.

Occupational dose monitoring

STUK will continue to participate in research on individual dose monitoring within the EURADOS collaboration. The main activity will be a study of the feasibility of the EC technical recommendations for monitoring individuals occupationally exposed to external radiation (EC Report Radiation Protection No 160, 2009). Other suggested topics of work include the organisation of intercomparison exercises and performance characteristics testing for individual monitoring techniques.

7.6.2 Internal dosimetry

The study to probe the ^{137}Cs body content and internal radiation doses affecting the population on a long-term scale will continue. The doses to man from naturally occurring radionuclides will also be further investigated.

The old mobile whole-body measurement unit has been replaced with a new one. A new background shield (chair) has been constructed and a detector stand is under construction. In the whole-body laboratory permanently situated in Helsinki, the old detector supports will be removed from the iron measurement chamber to give way to a new lung counter. The present whole body counter will be modified in order to optimise the use of semiconductor detectors and possibly some NaI(Tl) crystals. The data acquisition software will be harmonised with the Radionuclide Analytics Laboratory. The testing and calibration phase of the units will exploit both traditional and mathematical (voxel) phantoms. New measurement units will be used in research, service, and preparedness tasks.

Mathematical modelling will be applied to the development of the spectrometers used at STUK. These numerical models provide useful tool to improve and refine the measurement geometry of whole body counters. A particular focus will be how to take into account the uneven distribution of contamination in the body in measurement results. In addition, corrections to the measurement results due to height and weight differences among the measured people will be possible. The enhancement project will continue to a stationary whole-body counter. This stationary unit is a laboratory room with heavy (50 metric ton) background shielding constructed of old steel. Monte Carlo simulations will be heavily used in order to build a measurement set-up that can take full advantage of the very low background radiation level in this room. This laboratory will include the whole-body counter and a dedicated lung counter set-up.

7.7 Non-ionising radiation

There is a continuing concern among the general public on the electromagnetic fields generated by the new technology that utilises electromagnetic fields (EMF) and which is increasing rapidly. Body scanners used in airports and the wireless transfer of electric power are examples of this EMF technology. Research on the NIR risks and the development of methods for exposure assessment will be continued, particularly in those cases where human exposure can be expected to be a significant proportion of the exposure limit. In particular, body-mounted radio-transmitters are of great interest. EMF from mobile phone base stations will be systematically measured in order to provide information for the general public and guidance for the placement of antennas. Implementation of the new directive for EM fields increases the need to examine exposure conditions in workplaces. STUK will examine the magnetic fields in the MRI environment.

Due to the increasing popularity of skin tanning lamps, the potentially deleterious effects of solarium-derived UV radiation have become a public health concern, since the use of solaria has been linked to the development of melanoma. Melanoma is characterised by a high risk of haematogeneous metastases in the early stages of disease and it is the main reason for melanoma mortality. We have previously investigated the effect of solarium-derived UV-A radiation on the metastatic capacity of mouse melanoma, reporting a possible link between UV radiation exposure and melanoma metastasis. In the future, the UV-induced molecular changes in pulmonary melanoma metastasis will be studied utilising different *in vivo* imaging modalities. Our experiments will provide new information on the physiological processes of UV radiation in skin photobiology and the results may be used in the prevention of long-term detrimental health hazards derived from UV-induced reactions.

Actions promoting the well-being of MRI workers

The Finnish Institute of Occupational Health (FIOH) and STUK have applied for funding from the Finnish Work Environment Fund for a project aimed to improve the occupational safety and well-being of people working in the vicinity of MRI scanners. Some university hospitals, MRI manufacturers and the national Supervisory Authority for Welfare and Health (Valvira) will contribute to the project. The project is scheduled to be carried out between June 2011 and December 2013.

STUK's main interest in the project is to develop guidelines for safe working in strong magnetic fields and methods for exposure measurement. In addition, new ideas will be tested to restrict the electric fields induced in the human body by movement in a static magnetic field.

8 Publications

Original publications, proceedings and STUK-A-reports as well as selected reports cited in chapter 6

Aallos S-M. Patient radiation exposure in measurements of bone mineral density. Master's Thesis. Helsinki University of Technology, Department of Electrical and Communicatio ns Engineering, **2005** (In Finnish).

Aarnio PA, Ala-Heikkilä JJ, Isolankila A, Kuusi A, Moring M, Nikkinen M, Siiskonen T, Toivonen H, Ungar K, Zhang W. LINSSI: Database for gamma-ray spectrometry. Journal of Radioanalytical and Nuclear Chemistry **2008**; 276 (3): 631–637.

Ainsbury EA, Bakhanova E, Barquinero JF, Brai M, Chumak V, Correcher V, Darroudi F, Fattibene P, Gruel G, Guclu I, Horn S, Jaworska A, Kulka U, Lindholm C, Lloyd D, Longo A, Marrale M, Monteiro Gil O, Oestreicher U, Pajic J, Rakic B, Romm H, Trompier F, Veronese I, Voisin P, Vral A, Whitehouse CA, Wieser A, Woda C, Wojcik A, Rothkamm K. Retrospective dosimetry mechniques for external radiation exposures. Epub 2010 December 23. Radiation Protection Dosimetry **2010**. (20 pp.).

Alanko T, Puranen L, Hietanen M. Assessment of exposure to intermediate frequency electric fields and contact currents from a plasma ball. Epub 2011 May 2. Bioelectromagnetics **2011**. (8 pp.)

Algora A, Taín JL, Perez-Cerdan AB, Rubio B, Agramunt J, Caballero L, Nácher E, Jordan D, Molina F, Krasznahorkay A, Hunyadi MD, Gulyás J, Vitéz A, Csatlós M, Csige L, Äystö J, Penttilä H, Rinta-Antila S, Moore I, Eronen T, Jokinen A, Nieminen A, Hakala J, Karvonen P, Kankainen A, Hager U, Sonoda T, Saastamoinen A, Rissanen J, Kessler T, Weber C, Ronkainen J, Rahaman S, Elomaa V, Burkard K, Hüller W, Batist L, Gelletly W, Yoshida T, Nichols AL, Sonzogni A, Peräjärvi K. β-decay data requirements for reactor decay heat calculations: study of the possible source of the gamma-ray discrepancy in reactor heat summation calculations. In: Bersillon O, Gunsing F, Bauge E, Jacqmin R, Leray S (Eds.). Proceedings of the International Conference on Nuclear Data for Science and Technology 2007. 2007 Apr 22–27; Nice, France. EDP Sciences; **2008**. Epub 2008 May 21.

Allen S, Bassen H, D'Inzeo G, Hirata A, Jokela K, Lin J, Mann S, Matthes R, Roy C, Taki M, Wang J, Watanabe S. Dosimetry of high requency electromagnetic fields (100 kHz to 300 GHz). Chapter I In: Vecchia P, Matthes R, Ziegelberger G, Lin J, Saunders R, Swerdlow A (Eds.). Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz–300 GHz). – Review of the scientific evidence on dosimetry, biological effects, epidemiological observations, and health consequences concerning exposure to high frequency electromagnetic fields (100 kHz to 300 GHz). ICNIRP 16/2009. International Commission on Non-Ionizing Radiation Protection; **2009**. p. 1–89.

Ammann M. Finnish workshop on the restoration of contaminated residential areas after a nuclear accident: strategy generation and impact assessment. Journal of Environmental Radioactivity **2006**; 85: 299–313.

Ammann M, Peltonen T, Ilander T, Kuukankorpi S, Lahtinen J, Lemmelä H, Rantamäki M, Salonen T, Sarkanen A, Seppänen M, Siljamo P, Summanen T, Vesterbacka K. Design of the KETALE web application to improve collaboratorive emergency management. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008: 13. Østerås: Norwegian Radiation Protection Authority; **2008**. p. 162–167.

Ammann M, Peltonen T, Lahtinen J, Vesterbacka K, Summanen T, Seppänen M, Siljamo P, Sarkanen A, Rantamäki M. KETALE Web application to improve collaborative emergency management. In: French S, Romaszewski B, Zobel C (Eds.). Proceedings of the 7th International Conference on Information Systems for Crisis Response and Management. Defining Crisis Management 3.0. May **2010**, Seattle, USA.

Andersson KG, Nielsen SP, Thørring H, Hansen HS, Joensen HP, Isaksson M, Kostiainen E, Suolanen V, Pálsson SE. Improving ingestion dose modelling for the ARGOS and RODOS decision support systems: A Nordic initiative. In: Proceedings – Third European IRPA Congress, 14–18 June 2010, Helsinki, Finland. Helsinki: Nordic Society for Radiation Protection; **2011**. S04-05. p. 691–698.

Andersson U, Osterman P, Sjöström S, Johansen C, Henriksson R, Brännström T, Broholm H, Collatz Christensen H, Ahlbom A, Auvinen A, Feychting M, Lönn S, Kiuru A, Swerdlow A, Schoemaker M, Roos G, Malmer B. MNS16A minisatellite genotypes in relation to risk of glioma and meningioma and to glioblastoma outcome. International Journal of Cancer **2009**; 125: 968–972.

Andersson U, Schwartzbaum J, Wiklund F, Sjöström S, Liu Y, Tsavachidis S, Ahlbom A, Auvinen A, Collatz-Laier H, Feychting M, Johansen C, Kiuru A, Lönn S, Schoemaker MJ, Swerdlow AJ, Henriksson R, Bondy M, Melin B. A comprehensive study of the association between the EGFR and ERBB2 genes and glioma risk. Acta Oncologica **2010**; 49: 767–775.

Annanmäki M, Oksanen E, Venelampi E, Markkanen M. Radon in Finnish mines – regular monitoring since 1972. Proceedings of Seventh International Symposium on the Natural Radiation Environment (NRE-VII), Rhodes, Greece, 20–24 May 2002. In: Baxter MS (Ed.).Radioactivity in the Environment. Volume 7. Oxford: Elsevier Ltd.; **2005**. p. 657–664.

Anttila A, Leppänen A-P, Rissanen K, Ylipieti J. Concentrations of ^{137}Cs in summer pasture plants that reindeer feed on in the reindeer management area of Finland. Journal of Environmental Radioactivity **2011**; 102 (7): 659–666.

Aro L, Plamboeck AH, Rantavaara A, Strålberg E, Vetikko V. Sampling in forests for radionuclide analysis – General and practical guidance. NKS-183. Roskilde, Denmark Nordic Nuclear Safety Research; **2009**.

Arvela H. Review of seasonal variation in residential indoor radon. In: McLaughlin JP, Simopoulos SE, Steinhäusler F (Eds.). Radioactivity in the Environment, Volume 7. The Natural Radiation Environment VII. Seventh International Symposium on the Natural Radiation Environment, Rhodes, Greece, 20–24. May 2002. Elsevier **2005a**. p. 612–617.

Arvela H. Radon in Finland: Building regulations and raising public awareness. In: Valentin J, Cederlund T, Drake P, Finne IE, Glansholm A, Jaworska A, Paile W, Rahola T (Eds.). Radiological Protection in Transition – Proceedings of the XIV Regular Meeting of the Nordic Society for Radiation Protection, NSFS – Rättvik, Sweden, 27–31 August 2005. SSI Report 2005:15. Stockholm: Swedish Radiation Protection Authority; **2005b**. p. 221–224.

Arvela H. Indoor radon sources, remediation and prevention in new construction. In: Proceedings – Third European IRPA Congress, 14–18 June 2010, Helsinki, Finland. Helsinki: Nordic Society for Radiation Protection; **2011**. R12. p. 2991–3013.

Arvela H, Reisbacka H. Indoor radon mitigation. STUK-A229. Helsinki: Radiation and Nuclear Safety Authority; **2008a**. (In Finnish)

Arvela H, Reisbacka H. New indoor radon mitigation guides in Finland. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008:13. Østerås: Norwegian Radiation Protection Authority; **2008b**. p. 121–124.

Arvela H, Reisbacka H. Indoor radon mitigation. STUK-A237. Helsinki: Radiation and Nuclear Safety Authority; **2009**. (In Swedish)

Arvela H, Bergman J, Yrjölä R, Kurnitski J, Matilainen M, Järvinen P. Developments in radon-safe building in Finland. McLaughlin JP, Simopoulos SE, Steinhäusler F (Eds.). Radioactivity in the Environment, Volume 7. The Natural Radiation Environment VII. Seventh International Symposium on the Natural Radiation Environment, Rhodes, Greece, 20–24. May 2002. Elsevier **2005**. p. 618–623.

Arvela H, Mäkeläinen I, Reisbacka H. Radon policy in Finland, achievements and challenges. In: The Natural Radiation Environment, 8th International Symposium (NREVIII). 2007 Oct 7–12; Brazil. American Institute of Physics, AIP Conference Proceedings 1034. Melville New York, **2008a**. p. 435–437.

Arvela H, Valmari T, Reisbacka H, Niemelä H, Oinas T, Mäkeläinen I, Laitinen-Sorvari R. Radon campaigns – Status report 2008. STUK-A233. Helsinki: Radiation and Nuclear Safety Authority; **2008b**. (In Finnish)

Arvela H, Mäkeläinen I, Holmgren O, Reisbacka H. Radon prevention in new construction – Sample survey 2009. STUK-A244. Helsinki: Radiation and Nuclear Safety Authority; **2010**. (In Finnish)

Arvela H, Holmgren O, Reisbacka H. Radon prevention in new construction in Finland: a nationwide sample survey in 2009. Epub 2011 May 31. Radiation Protection Dosimetry **2011**. (10 pp.).

Auvinen A, Pershagen G. Indoor radon and deaths from lung cancer. Editorial. British Medical Journal **2009**; 338: 184–185.

Auvinen A, Salonen L, Pekkanen J, Pukkala E, Ilus T, Kurttio P. Radon and other natural radionuclides in drinking water and risk of stomach cancer: a case-cohort study in Finland. International Journal of Cancer **2005**; 114 (1): 109–113.

Auvinen A, Lahkola A, Tokola K, Kurttio P. Epidemiologic assessment of cancer risk from mobile phone use: where are we? In: PIERS 2006 Cambridge. Progress In Electromagnetics Research Symposium. Proceedings. March 26–29, **2006a**. Cambridge, Massachusetts, USA. p. 197–199.

Auvinen A, Toivo T, Tokola K. Epidemiological risk assessment of mobile phones and cancer: where can we improve? European Journal of Cancer Prevention **2006b**; 15 (6): 516–523.

Auvinen A, Lahkola L, Feychting M, Swerdlow AJ, Johansen C, Tynes T. Author's Response: Response to commentary: Meningioma and mobile phone use – a collaborative case-control study in five North European countries. International Journal of Epidemiology **2010**; 39: 1119.

Bartusková M, Malátova I, Berkovskyy V, Krajewski P, Ammann M, Filistovic V, Homma T, Horyna J, Kanyár B, Nedveckaite T, Vlasov O, Zvonova I. Radioecological assessments of the Iodine working group of IAEA's EMRAS programme: Presentation of input data and analysis of results of the prague scenario. Radioprotection **2009**; 44 (5): 295–299.

Baverstock K, Belyakov OV. Classical radiation biology, the bystander effect and paradigms: a reply. Human & Experimental Toxicology **2005**; 24: 537–542.

Baverstock K, Belyakov OV. Some important questions connected with non-targeted effects. Mutatation Research **2010**; 687 (1–2): 84–88.

Belli M, Salomaa S, Ottolenghi A. MELODI: The 'Multidisciplinary European LOw Dose Initiative'. Radiation Protection Dosimetry **2011**; 143 (2–4): 330–334.

Belyakov OV (Ed.). Non-targeted effects of ionising radiation. Proceedings of the RISCRAD specialised training course "Nontargeted effects of ionising radiation". STUK – Radiation and Nuclear Safety Authority, Helsinki, Finland 14–16 February 2005. STUK-A234. Helsinki: Radiation and Nuclear Safety Authority; **2008a**.

Belyakov O. Studies of ionising radiation induced bystander effects in 3D artificial tissue system and applications for radiation protection. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008b**. [CD-ROM, TS I.2.2: 2669 (10 pp.)]

Belyakov OV. Non-targeted biological effects of ionising radiation. Full paper of the refresher course, topic RC-2 Cellular and molecular effects. In: IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. [Epub **2009**, 22 pp.]

Belyakov OV, Mitchell SA, Parikh D, Randers-Pehrson G, Marino SA, Amundson SA, Geard CR, Brenner DJ. Biological effects in unirradiated human tissue induced by radiation damage up to 1 mm away. PNAS (Proceedings of the National Acedemy of Sciences of the United States of America) **2005**; 102 (40): 14203–14208.

Belyakov OV, Folkard M, Mothersill C, Prise KM, Michael BD. Bystander-induced differentiation: A major response to targeted irradiation of a urothelial explant model. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis **2006a**; 597 (1–2): 43–49.

Belyakov OV, Mononen H, Perälä M. Studies of Non-Targeted Effects of Ionising Radiation. In: Proceedings of the Second European International Radiation Protection Association (IRPA) Congress. 2006 May 15–19; Paris, France. Paris: Société Francaise de Radioprotection, International Radiation Protection Association; **2006b**.

Beresford NA, Barnett CL, Brown JE, Cheng JJ, Copplestone D, Filistovic V, Hosseini A, Howard BJ, Jones SR, Kamboj S, Kryshev A, Nedveckaite T, Olyslaegers G, Saxén R, Sazykina T, Vives i Batlle J, Vives-Lynch S, Yankovich T, Yu C. Inter-comparison of models to estimate radionuclide activity concentrations in non-human biota. Radiation and Environmental Biophysics **2008**; 47: 491–514.

Bethke L, Murray A, Webb E, Schoemaker M, Muir K, McKinney P, Hepworth S, Dimitropoulou P, Lophatananon A, Feychting M, Lönn S, Ahlbom A, Malmer B, Henriksson R, Auvinen A, Kiuru A, Salminen T, Johansen C, Christensen Helle Collatz, Kosteljanetz M, Swerdlow A, Houlston R. Comprehensive analysis of DNA repair gene variants and risk of meningioma. Journal of the National Cancer Institute **2008a**; 100 (4): 270–276.

Bethke L, Murray A, Webb E, Schoemaker M, Muir K, McKinney P, Hepworth S, Dimitropoulou P, Lophatananon A, Feychting M, Lönn S, Ahlbom A, Malmer B, Henriksson R, Auvinen A, Kiuru A, Salminen T, Johansen C, Collatz Christensen H, Kosteljanetz M, Swerdlow A, Houlston R. Comprehensive analysis of the role of DNA repair gene polymorphisms on risk of glioma. Human Molecular Genetics **2008b**; 17 (6): 800–805.

Bethke L, Sullivan K, Webb E, Murray A, Schoemaker M, Auvinen A, Kiuru A, Salminen T, Johansen C, Christensen HC, Muir K, McKinney P, Hepworth S, Dimitropoulou P, Lophatananon A, Feychting M, Lönn S, Ahlbom A, Malmer B, Henriksson R, Swerdlow A, Houlston R. The common D302H variant of CASP8 is associated with risk of glioma. Short Communication. Cancer Epidemiology, Biomarkers & Prevention **2008c**; 17 (4): 987–989.

Bethke L, Murray A, Webb E, Schoemaker M, Muir K, McKinney P, Hepworth S, Dimitropoulou P, Lophatananon A, Feychting M, Lönn S, Ahlbom A, Malmer B, Henriksson R, Auvinen A, Kiuru A, Salminen T, Johansen C, Collatz Christensen H, Kosteljanetz M, Swerdlow A, Houlston R. Functional polymorphisms in folate metabolism genes influence the risk of meningioma and glioma. Cancer Epidemiology, Biomarkers & Prevention **2008d**; 17 (5): 1195–1202.

Bethke L, Sullivan K, Webb E, Murray A, Schoemaker M, Auvinen A, Kiuru A, Salminen T, Johansen C, Collatz Christensen H, Muir K, McKinney P, Hepworth S, Dimitropoulou P, Lophatananon A, Feychting M, Lönn S, Ahlbom A, Malmer B, Henriksson R, Swerdlow A, Houlston R. *CASP8* D302H and meningioma risk: an analysis of five case-control series. Cancer Letters **2009**; 273 (2): 312–315.

Boström G, Gonçalves JGM, Okko O, Sequeira V. 3D laser modelling of the Onkalo geological repository. In: Proceedings of the 49th Annual Meeting of the Institute of Nuclear Material Management (INMM). **2008** Jul 13–17; Nashville, Tennessee, USA. [CD-ROM]

Bravin A, Keyriläinen J, Fernández M, Fiedler S, Nemoz C, Karjalainen-Lindsberg M-L, Tenhunen M, Virkkunen P, Leidenius M, von Smitten K, Sipilä P, Suortti P. High-resolution CT by diffraction-enhanced x-ray imaging: mapping of breast tissue samples and comparison with their histo-pathology. Physics in Medicine and Biology **2007**; 52: 2197–2211.

Breitner D. Geochemical and mineralogical investigation of overburden profiles in glaciated terrain, Finland – implication for the assessment of radon emission. Doctoral Thesis. Lithospere Fluid Research Laboratory, Eötvös University, Budapest; **2011**. Accepted for publication.

Breitner D, Turtiainen T, Arvela H, Vesterbacka P, Johanson B, Lehtonen M, Hellmuth K-H, Szabó C. Multidisciplinary analysis of Finnish esker sediment in radon source identification. Science of the Total Environment **2008**; 405 (1–3): 129–139.

Breitner D, Arvela H, Hellmuth K-H, Renvall T. Effect of moisture content on emanation at different grain size fractions – a pilot study on granitic esker sand sample. Journal of Environmental Radioactivity **2010**; 101: 1002–1006.

Brown J, Gjelsvik R, Holm E, Roos P, Saxén R, Outola I. Filling knowledge gaps in radiation protection methodologies for non human biota. Final summary report. NKS-187. Roskilde, Denmark: Nordic Nuclear Safety Research; **2009**.

But A, Kurttio P, Heinävaara S, Auvinen A. No increase in thyroid cancer among children and adolescents in Finland due to Chernobyl accident. European Journal of Cancer. European Journal of Cancer **2006**; 42: 1167–1171.

Büermann L, O'Brien M, Butler D, Csete I, Gabris F, Hakanen A, Lee J-H, Palmer M, Saito N, de Vries W. Comparison of national air kerma standards for ISO 4037 narrow spectrum series in the range 30 kV to 300 kV. EUROMET 545: Final report 25/09/2008. Metrologia **2008**; 45 Technical Suppl.: 06013.

Calmon P, Thiry Y, Zibold G, Rantavaara A, Fesenko S. Transfer parameter values in temperate forest ecosystems: a review. Journal of Environmental Radioactivity **2009**; 100: 757–766.

Cardis E, Vrijheid M , Blettner M, Gilbert E, Hakama M, Hill C, Howe G, Kaldor J, Muirhead CR, Schubauer-Berigan M, Yoshimura T, Bermann F, Cowper G, Fix J, Hacker C, Heinmiller B, Marshall M, Thierry-Chef I, Utterback D, Ahn Y-O, Amoros E, Ashmore P, Auvinen A, Bae J-M, Bernar Solano J, Biau A, Combalot E, Deboodt P, Diez Sacristan A, Eklof M, Engels H, Engholm G, Gulis G, Habib R, Holan K, Hyvonen H, Kerekes A, Kurtinaitis J, Malker H, Martuzzi M, Mastauskas A, Monnet A, Moser M, Murata M, Pearce MS, Richardson DB, Rodriguez-Artalejo F, Rogel A, Tardy H, Telle-Lamberton M, Turai I, Usel M, Veress K. Cancer risk following low doses of ionizing radiation – a retrospective cohort study in 15 countries. British Medical Journal **2005**; 331: 77–80.

Cardis E, Richardson L, Deltour I, Armstrong B, Feychting M, Johansen C; Kilkenny M, McKinney P, Modan B, Sadetzki S, Schüz J, Swerdlow A, Vrijheid M, Auvinen A, Berg G, Blettner M, Bowman J, Brown J, Chetrit A, Christensen HC, Cook A, Hepworth S, Giles G, Hours M, Iavarone I, Hakak AJ, Klaeboe L, Krewski D, Lagorio S, Lönn S, Mann S, McBride M, Muir K, Nadon L, Parent M-E, Pearce N, Salminen T, Schoemaker M, Schlehofer B, Siemiatycki J, Taki M, Takebayashi T, Tynes T, van Tongeren M, Vecchia P, Wiart J, Woodward A, Yamaguchi N. The INTERPHONE study: Design, epidemiological methods, and description of the study population. European Journal of Epidemiology **2007a**; 22 (9):647 – 664.

Cardis E, Vrijheid M, Blettner M, Gilbert E, Hakama M, Hill C, Howe G, Kaldor J, Muirhead CR, Schubauer-Berigan M, Yoshimura T, Bermann F, Cowper G, Fix J, Hacker C, Heinmiller B, Marshall M, Thierry-Chef I, Utterback D, Ahn Y-O, Amoros E, Ashmore P, Auvinen A, Bae J-M, Bernar JS, Biau A, Combalot E, Deboodt P, Diez Sacristan A, Eklof M, Engels H, Engholm G, Gulis G, Habib RR, Holan K, Hyvonen H, Kerekes A, Kurtinaitis J, Malker H, Martuzzi M, Mastauskas A, Monnet A, Moser M, Pearce MS, Richardson DB, Rodriguez-Artalejo F, Rogel A, Tardy H, Telle-Lamberton M, Turai I, Usel M, Veress K. The 15-country collaborative study of cancer risk among radiation workers in the nuclear industry: Estimates of radiation-related cancer risks. Radiation Research **2007b**; 167: 396 – 416.

Cardis E, Deltour I, Vrijheid M, Combalot E, Moissonnier M, Tardy H, Armstrong B, Giles G, Brown J; Siemiatycki J, Parent ME, Nadon L, Krewski D, McBride ML, Johansen C, Collatz Christensen H, Auvinen A, Kurttio P, Lahkola A, Salminen T, Hours M, Bernard M, Montestruq L,: Schüz J, Berg-Beckhoff G, Schlehofer B, Blettner M, Sadetzki S, Chetrit A, Jarus-Hakak A, Lagorio S, Iavarone I, Takebayashi T, Yamaguchi N, Woodward A, Cook A, Pearce N, Tynes T, Blaasaas KG, Klaeboe L, Feychting M, Lönn S, Ahlbom A, McKinney PA, Hepworth SJ, Muir KR, Swerdlow AJ, Schoemaker MJ (INTERPHONE Study Group). Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case–control study. International Journal of Epidemiology **2010**: 39 (3): 675 – 964.

Cerny J, Moltz DM, Lee DW, Peräjärvi K, Barquest BR, Grossman LE, Jeong W, Jewett CC. Reinvestigation of the direct two-proton decay of the long-lived isomer 94Ag*m* [0.4 s, 6.7 MeV, (21*þ*)]. Physical Review Letters **2009**; 103: 152502-1 – 152502-4.

Darby S, Hill D, Auvinen A, Barros-Dios JM, Baysson H, Bochicchio F, Deo H, Falk R, Forastiere F, Hakama M, Heid I, Kreienbrock L, Kreutzer M, Lagarde F, Mäkeläinen I, Muirhead C, Obereigner W, Pershagen G, Ruano-Ravina A, Ruosteenoja E, Schaffrath-Rosario A, Tirmarche M, Tomasek L, Whitley E, Wichmann H-E, Doll R. Radon in homes and lung cancer risk: collaborative analysis of individual data from 13 European case-control studies. British Medical Journal **2005**; 330: 223 – 226.

Darby S, Hill D, Deo H, Auvinen A, Barros-Dios JM, Baysson H, Bochicchio F, Falk R, Farchi S, Figueiras A, Hakama M, Heid I, Hunter N, Kreienbrock L, Kreuzer M, Lagarde FC, Mäkeläinen I, Muirhead C, Oberaigner W, Pershagen G, Ruosteenoja E, Schaffrath Rosario A, Tirmarche M, Tomášek L, Whitley E, Wichmann H-E, Doll R. Residential radon and lung cancer – detailed results of a collaborative analysis of individual data on 7148 persons with lung cancer and 14 208 persons without lung cancer from 13 epidemiologic studies in Europe. Scandinavian Journal of Work, Environment & Health **2006**; 32 Suppl 1: 1 – 84.

Dawe AS, Nylund R, Leszczynski D, Kuster N, Reader T, De Pomerai DI. Continuous wave and simulated GSM exposure at 1.8 W/kg and 1.8 GHz do not induce hsp16-1 heat-shock gene expression in *Caenorhabditis elegans*. Bioelectromagnetics **2008**; 29 (2): 92–99.

Deltour I, Johansen C, Auvinen A, Feychting M, Klaeboe L, Schuez J. Time trends in brain tumor incidence rates in Denmark, Finland, Norway and Sweden, 1974–2003. Journal of the National Cancer Institute **2009**; 101: 1721–1724.

Deltour I, Johansen C, Auvinen A, Feychting M, Klaeboe L, Schüz J. Response. Journal of the National Cancer Institute **2010**: 201 (10): 742–743.

Deltour I, Auvinen A, Feychting M, Johansen C, Klaeboe L, Sankila R, Schüz J. Mobile phone use and incidence of glioma in the Nordic countries 1979–2008: Consistency check. **Submitted** to Epidemiology.

Deperas J, Szłuinska M, Deperas-Kaminska M, Edwards A, Lloyd D, Lindholm C, Romm H, Roy L, Moss R, Morand J, Wojcik A. CABAS: A freely available PC programme for fitting calibration curves in chromosome aberration dosimetry. Radiation Protection Dosimetry **2007**; 124 (2): 115–123.

Di Giorgio M, Barquinero JF, Vallerga MB, Radl A, Taja MR, Seoane A, De Luca J, Stuck Oliveira M, Valdivia P, Carcia Lima O, Lamadrid A, Conzález Mesa J, Romero Aguilera I, Mandina Cardoso T, Guerrero Carvajal C, Arceo Maldonado C, Espinoza ME, Martinez-López W, Méndez-Acuna M, Di Tomasso M, Roy L, Lindholm C, Romm H, Güclü I, Lloyd DC. Biological Dosimetry Intercomparison Exercise: An Evaluation of Triage and Routine Mode Results by Robust Methods, Radiation Research **2011**; 175: 638–649.

Dowdall M, Selnæs ØG, Standring WJF, Nielsen SP, del Risco Norrlid L, Pálsson SE, Renvall T, Sing Sidhu R. An emergency response intercomparison exercise using a synthetically generated gamma-ray spectrum. Journal of Radioanalytical and Nuclear Chemistry **2010**; 283 (1): 31–43.

Drazil K. Final report on supplementary comparison EUROMET.EM.RF-S25 (EURAMET project 819): Comparison of electrical field strength measurements above 1 GHz. Metrologia **2011**; 48, Technical Supplement.

Drozdovitch V, Bouville A, Chobanova N, Filistovic V, Ilus T, Kovacic M, Malatova I, Moser M, Nedveckaite T, Völkle H, Cardis E. Radiation exposure to the population of Europe following the Chernobyl accident. Radiation Protection Dosimetry **2007**; 123 (4): 515–528.

Edwards AA, Lindholm C,Darroudi F, Stephan G, Romm H, Barquinero J, Barrios L, Caballin MR, Roy L, Whitehouse CA, Tawn EJ, Moquet J, Lloyd DC, Voisin P. Review of translocations detected by fish for retrospective biological dosimetry applications. Radiation Protection Dosimetry **2005**; 113 (4): 396–402.

Envall J, Ylianttila L, Moseley H, Coleman A, Durak M, Kärhä P, Ikonen E. Investigation of comparison methods for UVA irradiance responsivity calibration facilities. Metrologia **2006**; 43: 27–30.

European Commission. Report of High Level and Expert group on European low dose risk research – radiation protection. EUR 23884. Luxembourg: Office for Official Publications of the European Communities; **2009**. [Members of the High Level and Expert Group HLEG: Weiss W, Legrain P, Repussard J, Salomaa S, Belli M, Walker H, Kelly GN, Atkinson MJ, Cardis E, Cox R, Elliott AT, Hall J, Harms-Ringdahl Mats, Jourdain J-R, Ottolenghi A, Goodhead D.]

Falzone N, Huyser C, Fourie F, Toivo T, Leszczynski D, Franken D. In vitro effect of pulsed 900 MHz GSM radiation on mitochondrial membrane potential and motility of human spermatozoa. Bioelectromagnetics **2008**; 29 (4): 268–276.

Falzone N, Huyser C, Franken DR, Leszczynski D. Mobile phone radiation does not induce pro-apoptosis effect in human spermatozoa. Radiation Research **2010**; 174 (2): 169–176.

Falzone N, Huyser C, Becker P, Leszczynski D, Franken DR. The effect of pulsed 900-MHz GSM mobile phone radiation on the acrosome reaction, head morphometry and zona binding of human spermatozoa. International Journal of Andrology **2011**; 34 (1): 20–26.

Feychting M, Ahlbom A, Juutilainen J, Veyret B, Vainio H, Kheifets L, Auvinen A, Saunders RR. Recent Research on EMF and Health Risks. SSI Rapport 2007:04. Stockholm: SSI; **2007**.

Godske Friberg E, Almen A, Einarsson G, Järvinen H, Leitz W, Waltenburg H, Bly R. Doses from pediatric CT examinations and level of optimization of the scan protocols in the Nordic countries. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008: 13. Østerås: Norwegian Radiation Protection Authority; **2008**. p. 41–50.

Hakanen A, Siiskonen T, Pöllänen R, Kosunen A, Turunen A, Belyakov O. Design, spectrum measurements and simulations for a ^{238}Pu α-particle irradiator for bystander effect and genomic instability experiments. Applied Radiation and Isotopes **2006**; 64: 864–867.

Hakanen A, Sipilä P, Sahla T. Characteristics of a ^{85}Kr beta-particle source applied in series 1 reference irradiations of ™DIS-1 Direct Ion Storage dosemeters. Radiation Protection Dosimetry **2007a**; 124:103–106.

Hakanen A, Kosunen A, Pöyry P, Tapiovaara M. Determination of conversion factors from air kerma to operational dose equivalent quantities for low energy x-ray spectra. Radiation Protection Dosimetry **2007b**; 125 (1–4): 198–204. Hakanen A, Siiskonen T, Turunen J. Simulated and measured spectral characteristics of ^{137}Cs reference radiation beams. Radiation Protection Dosimetry **2009**; 133 (2): 81–88.

Hansen H, Nielsen S, Andersson K, Thorring H, Joensen H, Isaksson M, Kostiainen E, Suolanen V, Sigurgeirsson, Palsson S. Effect of nordic diets on ecosys model predictions of ingestion doses. Radiation Protection Dosimetry **2010**; 140 (2): 182–190.

Hartikka H, Heinävaara S, Mäntylä R, Kähärä V, Kurttio P, Auvinen A. Mobile phone use and location of glioma: a case – case analysis. Bioelectromagnetics **2009**; 30 (3): 176–182.

Heikkinen P, Ernst H, Huuskonen H, Komulainen H, Kumlin T, Mäki-Paakkanen J, Puranen L, Juutilainen J. No effects of radiofrequency radiation on 3-Chloro-4-(dicholoromethyl)-5-hydroxy-2(5H)-furanone-induced tumorigenesis in female Wistar rats. Radiation Research **2006**; 166: 397–408.

Heinävaara S, Toikkanen S, Pasanen K, Verkasalo PK, Kurttio P, Auvinen A. Cancer incidence in the vicinity of Finnish nuclear power plants: an emphasis on childhood leukemia. Cancer Causes and Control **2010**; 21 (4): 587–595.

Heinävaara S, Tokola K, Kurttio P, Auvinen A. Validation of exposure assessment and assessment of recruitment methods for a prospective cohort study of mobile phone users (COSMOS) in Finland: a pilot study. Epub 2011 March 8. Environmental Health **2011**; 10 (14). (9 pp.).

Hellmuth KH, Read D, Black S, Buckby T, Oziabkin S & V, Marcos N, Markovaara-Koivisto M, Siitari-Kauppi M, Kelokaski M, Proust T, Vaganov P, Traber D, Tarvainen T, Backman B, Hatakka T, Savolainen H, Kaija J, Blomqvist R, Rasilainen K, Pitkänen P, Löfman J, Luukkunen A, Partamies S. Geochemical fluxes in the geosphere: quantitative understanding by identification and verification of processes. In: Buckau G, Kienzler B, Duro L, Montoya V (Eds.). 2nd Annual Workshop Proceedings of the Integrated Project "Fundamental Processes of Radionuclide Migration" – 6th EC FP IP FUNMIG. 2006 Nov 21–23, Stockholm; Sweden. SKB Technical report TR-07-05 **2007**: 139–147.

Herrmann J, Outola I, Ikäheimonen TK. Radionuclides in seawater. In: Radioactivity in the Baltic Sea 1999–2006. HELCOM thematic assessment. Baltic Sea Environment Proceedings No. 117. Helsinki: HELCOM (Helsinki Comission, Baltic Marine Environment Protection Commission); **2009**. p. 18–24.

Hirvonen-Kari M, Järvinen H, Kivisaari L. Clinical audits and regulatory inspections – double efforts and expenses for radiation protection. Acta Radiologica **2010**; 6: 619–624.

Hoffman I, Ungar K, Bean M, Pöllänen R, Ihantola, S, Toivonen H, Karhunen T, Pelikan A. Direct Alpha Analysis for Forensic Samples (DAAFS): Techniques, applications, and results. In: Proceedings – Third European IRPA Congress, 14–18 June 2010, Helsinki, Finland. Helsinki: Nordic Society for Radiation Protection; **2011** P11-05. p. 1801–1806.

Hosseini A, Thørring H, Brown JE, Saxén R, Ilus E. Transfer of radionuclides in aquatic ecosystems – a comprehensive database for use in environmental impact assessment. Journal of Environmental Radioactivity **2008**; 99: 1408–1429.

Howard BJ, Beresford NA, Barnett CL, Rantavaara A, Rissanen K, Reales N, Gallay F, Papachristodoulou C, Ioannides K, Nisbet AF, Hesketh N, Oughton D, Bay I. A revised compendium of countermeasures for the management of food production systems. In: Strand P, Børretzen P, Jølle T (Eds). Proceedings from the 2nd International Conference on Radioactivity in the Environment. 2–6 October 2005, Nice, France. Østerås, Norway: Norwegian Radiation Protection Authority; **2005**. p. 435–438.

Huikari J, Muikku M, Pusa S. A new mobile whole-body counter for measurement of internal contamination in Finland. In: Maatela P, Korpela S (Eds.). Symposium Proceedings. NBC 2009. 7th Symposium on CBRNE threats. 8 – 11 June, 2009, Jyväskylä, Finland. Defence Forces Technical Research Centre, Publications 18. Helsinki: Defence Forces Technical Research Centre; **2009**. p. 217 – 221.

Huikari J, Pusa S, Muikku M. Whole-body counters for measurement of internal contamination in Finland. In: Proceedings – Third European IRPA Congress, 14 – 18 June 2010, Helsinki, Finland. Helsinki: Nordic Society for Radiation Protection; **2011**. P12-03. p. 1893 – 1899.

Hutri K-L. An approach to palaeoseismicity in the Olkiluoto (sea) area during the early Holocene. Academic dissertation. STUK-A222. Helsinki: Radiation and Nuclear Safety Authority; **2007**.

Hülsen G, Gröbner J, Bais A, Blumthaler M, Disterhoft P, Johnsen B, Lantz KO, Meleti C, Schreder J, Vilaplana Guerrero JM, Ylianttila L. Intercomparison of erythemal broadband radiometers calibrated by seven UV calibration facilities in Europe and the U.S.A. Atmospheric Chemistry and Physics **2008**; 8 (16): 4865 – 4875.

Höytö A, Sihvonen A-P, Alhonen L, Juutilainen J, Naarala J. Modest increase in temperature affects ODC activity in L929 cells: low-level radiofrequency radiation does not. Radiation and Environmental Biophysics **2006**; 45 (3): 231 – 235.

Ihantola S. Surface sampling methods for non-destructive radionuclide analysis. Master's Thesis. Helsinki University of Technology, Faculty of Information and Natural Sciences; **2009**.

Ikäheimonen TK. Plutonium in the Baltic Sea sediments. In: Strand P, Børretzen P, Jølle T (Eds.). Proceedings from the 2nd International Conference on Radioactivity in the Environment. 2 – 6 October 2005, Nice, France. Østerås, Norway: Norwegian Radiation Protection Authority; **2005**. p. 581 – 584.

Ikäheimonen TK (Ed.). Environmental radioactivity in Finland – 20 years since the Chernobyl accident. A Symposium, April 25 – 26, 2006 in Helsinki, Finland. STUK-A217. Helsinki: Radiation and Nuclear Safety Authority; **2006**. (41 articles in Finnish, 6 articles in English)

Ikäheimonen TK, Outola I. Data quality. In: Radioactivity in the Baltic Sea 1999 – 2006. HELCOM thematic assessment. Baltic Sea Environment Proceedings No. 117. Helsinki: HELCOM (Helsinki Comission, Baltic Marine Environment Protection Commission); **2009**. p. 54 – 60.

Ikäheimonen TK, Vartti V-P. An intercomparison of radionuclide analyses in a Baltic Sea sediment sample. Appendix. In: Ilus E, Mattila J, Nielsen SP, Jakobson E, Herrmann J, Graveris V, Vilimaite-Silobritiene B, Suplinska M, Stepanov A, Lüning M. Long-lived radionuclides in the seabed of the Baltic Sea. Report of the sediment baseline study of HELCOM MORS-PRO in 2000 – 2005. Baltic Sea Environment Proceedings No. 110. Helsinki: Helsinki Commission, Baltic Marine Environment Protection Commission; **2007**. p. 25 – 41.

Ikäheimonen TK, Klemola S, Ilus E, Vartti V-P, Mattila J. Monitoring of radionuclides in the vicinities of Finnish nuclear power plants in 1999–2001. STUK-A218. Helsinki: Radiation and Nuclear Safety Authority; **2006a**.

Ikäheimonen T, Klemola S, Vesterbacka P. Towards quality excellence in radiochemical laboratories at STUK, Finland. In: Povinec PP, Sanchez-Cabeza JA (Eds.). Radionuclides in the Environment, Volume 8. Elsevier Ltd.; **2006b**. p. 629–639.

Ikäheimonen TK, Mustonen R, Saxén R. Half a century of radioecological research and surveillance at STUK. Radioprotection **2009a**; 44 (5): 607–612.

Ikäheimonen TK, Outola I, Vartti V-P, Kotilainen P. Radioactivity in the Baltic Sea: inventories and temporal trends of ^{137}Cs and ^{90}Sr in water and sediments. Journal of Radioanalytical and Nuclear Chemistry **2009b**; 282 (2): 419–425.

Ilus E (Ed.). Proceedings of the Summary Seminar within the NKS-B Programme 2002–2005. 24–25 October 2005, Tartu, Estonia. NKS-140. Roskilde, Denmark: Nordic Nuclear Safety Research; **2006**.

Ilus E. The Chernobyl accident and the Baltic Sea. Boreal Environmental Research **2007**; 12: 1–10.

Ilus E. Environmental effects of thermal and radioactive discharges from nuclear power plants in the boreal brackish-water conditions of the northern Baltic Sea. Academic dissertation. STUK-A238. Helsinki: Radiation and Nuclear Safety Authority; **2009**.

Ilus E, Keskitalo J. The response of phytoplankton to increased tempereture in the Loviisa archipelago, Gulf of Finland. Boreal Environment Research **2008**; 13: 503–516.

Ilus E, Saxén R. Accumulation of Chernobyl-derived ^{137}Cs in bottom sediments of some Finnish lakes. Journal of Environmental Radioactivity **2005**; 82: 199–221.

Ilus E, Klemola S, Ikäheimonen TK. Radiocaesium in seals and terns off the Finnish coast after the Chernobyl accident. In: Strand P, Børretzen P, Jølle T (Eds.). Proceedings from the 2nd International Conference on Radioactivity in the Environment. 2–6 October 2005, Nice, France. Østerås, Norway: Norwegian Radiation Protection Authority; **2005**. p. 502–505.

Ilus E, Vartti V-P, Ikäheimonen TK, Mattila J. Recent observations of ^{99}Tc in Finnish coastal waters. In: Isotopes in Environmental Studies. Aquatic Forum 2004. Proceedings of an international conference held in Monaco, 25–29 October 2004. Conference & Symposium Papers 26/P. Vienna: IAEA; **2006**. p. 303–306.

Ilus E, Mattila J, Nielsen SP, Jakobson E, Herrmann J, Graveris V, Vilimaite-Silobritiene B, Suplinska M, Stepanov A, Lüning M. Long-lived radionuclides in the seabed of the Baltic Sea. Report of the sediment baseline study of HELCOM MORS-PRO in 2000–2005. Baltic Sea Environment Proceedings No. 110. Helsinki: Helsinki Commission, Baltic Marine Environment Protection Commission; **2007**.

Ilus E, Klemola S, Vartti V-P, Mattila J, Ikäheimonen TK. Monitoring of radionuclides in the vicinities of Finnish nuclear power plants in 2002–2004. STUK-A227. Helsinki: Radiation and Nuclear Safety Authority; **2008**.

Ilvonen S, Sihvonen A-P, Kärkkäinen K, Sarvas J. Numerical assessment of induced ELF xurrents in the human head due to the battery current of a digital mobile phone. Bioelectromagnetics **2005**; 26: 648–656.

Ilvonen S, Toivonen T, Toivo T, Uusitupa T, Laakso I. Numerical specific absorption rate analysis and measurement of a small indoor base station antenna. Microwave and Optical Technology Letters **2008**; 50 (10): 2516–2521.

Inn KGW, Hall E, Woodward JT, Stewart B, Pöllänen R, Selvig L, Turner S, Outola I, Nour S, Kurosaki H, LaRosa J, Schultz M, Lin Z, Yu Z, McMahon C. Use of thin collodion films to prevent recoil-ion contamination of alpha-spectrometry detectors. Journal of Radioanalytical and Nuclear Chemistry **2008**; 276 (2): 385–390.

Jartti P, Pukkala E, Vartiainen E, Uitti J, Auvinen A. Cancer incidence among physicians occupationally exposed to ionising radiation in Finland. Scandinavian Journal of Work, Environment & Health **2006**; 32 (5): 368–373.

Jaworska A, Lindholm C, Stricklin D. Nordic collaboration within biological dosimetry. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008**. [CD-ROM, TS I.1.3: 932 (5 pp.)]

Jokela K. Assessment of complex EMF exposure situations including inhomogeneous field distribution. Health Physics **2007**; 92: 531–540.

Jokela K, Nyberg H (Eds.). Electromagnetic fields. Radiation and Nuclear Safety Series, Part 6. Helsinki: Radiation and Nuclear Safety Authority; **2006**. (In Finnish)

Jokela K, Saunders RD. Physiologic and dosimetric considerations for limiting electric fields induced in the body by movement in a static magnetic field. Health Physics **2011**; 100 (6): 641–653.

Jokelainen I, Kosunen A. Comparison of calibration methods of plane parallel ionization chambers for electron beam dosimetry. In: Book of Extended Synopses. IAEA-CN-182. International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS). **2010** Nov 9–12; Vienna, Austria. p. 271–272.

Jokelainen I, Sipilä P, Järvinen H. Detectors for brachytherapy dosimetry: Response as a function of photon energy. In: Book of Extended Synopses. IAEA-CN-182. International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS). **2010** Nov 9–12; Vienna, Austria. p. 331–332.

Jokelainen L, Vesterbacka P, Lehto J. Method validation in solvent extraction for ^{210}Po determination from groundwaters. Radiochimica Acta **2010**; 98: 91–97.

Jones SR, Brown JE, Thørring H, Saxén R, Vives J. Radiation doses to aquatic organisms from natural radionuclides. In: Protection of the environment from the effects of ionizing radiation. Contributed papers of an international conference, Stockholm, 6–10 October 2003. STI/PUB/1229 Companion CD. Vienna: International Atomic Energy Agency; **2005**. p. 255–258. [CD-ROM]

Jussila P. Thermomechanics of swelling unsaturated porous media. Compacted bentonite clay in spent fuel disposal. Acedemic dissertation. STUK-A223. Helsinki: Radiation and Nuclear Safety Authority; **2007**.

Järvinen H. Double dosimetry with recommendations. In: Comissariat à L'Énergie Atomique (CEA). Radiation protection dosimetry in medicine. Report of the working group no 9 of the European radiation dosimetry group (Eurados). CEA-R-6220. Gif-Sur-Yvette Cedex: CEA; **2009**.

Järvinen H, Buls N, Clerinx P, Jansen J, Miljanić S, Nikodemová D, Ranogajec-Komor M, d'Errico F. Overview of double dosimetry procedures for the determination of the effective dose to the interventional radiology staff. Radiation Protection Dosimetry **2008a**; 129 (1–3): 333–339.

Järvinen H, Buls N, Clerinx P, Miljanić S, Nikodemová D, Ranogajex-Komor M, Struelens L, d'Errico F. Comparison of double dosimetry algorithms for estimating the effective dose in occupational dosimetry of interventional radiology staff. Radiation Protection Dosimetry **2008b**; 131 (1): 80–86.

Kamenopoulou V, van Dijk JWE, Ambrosi P, Bolognese-Milsztajn T, Castellani CM, Currivan L, Falk R, Fantuzzi E, Figel M, Garcia Alves GA, Ginjaume M, Janzekovic H, Kluszczynski D, Lopez MA, Luszik-Bhadra M, Olko P, Roed H, Stadtmann H, Vanhavere F, Vartiainen E, Wahl W, Weeks A, Wernli Ch. Aspects of harmonisation of individual monitoring for external radiation in Europe: Conclusions of a EURADOS action. Radiation Protection Dosimetry **2006**; 118 (2): 139–143.

Kantala T. Clean-up actions in food industry plants and their surroundings in a radioactive contamination situation. STUK-A212. Helsinki: Radiation and Nuclear Safety Authority; **2005**. (In Finnish)

Kapanen M, Tenhunen M, Hämäläinen T, Sipilä P, Parkkinen R, Järvinen H. Analysis of quality control data of eight modern radiotherapy linear accelerators: the short- and long-term behaviours of the outputs and the reproducibility of quality control measurements. Physics in Medicine and Biology **2006a**; 51 (14): 3581–3592.

Kapanen M, Tenhunen M, Parkkinen R, Sipilä P, Järvinen H. The influence of output measurement time interval and tolerance on treatment dose deviation in photon external beam radiotherapy. Physics in Medicine and Biology **2006b**; 51 (19): 4857–4867.

Kapanen M, Sipilä P, Bly R, Järvinen H, Tenhunen M. Accuracy of central axis dose calculations for photon external radiotherapy beams in Finland: The quality of local beam data and the use of averaged data. Radiotherapy and Oncology **2008**; 86 (2): 264–271.

Karinen A, Heinävaara S, Nylund R, Leszczynski D. Mobile phone radiation might alter protein expression in human skin. BMC Genomics **2008**; 9: 77. (5 pp.)

Karpas Z, Paz-Tal O, Lorber A, Salonen L, Komulainen H, Auvinen A, Saha H, Kurttio P. Urine, hair and nails as indicators for ingestion of uranium in drinking water. Health Physics **2005a**; 88 (3): 229–242.

Karpas Z, Lorber A, Sela H, Paz-Tal O, Hagag Y, Kurttio P, Salonen L. Measurement of the $^{234}U/^{238}U$ ratio by MC-ICPMS in drinking water, hair, nails and urine as an indicator of uranium exposure source. Health Physics **2005b**; 89 (4): 315–321.

Karpas Z, Lorber A, Sela H, Paz-Tal O, Hagag Y, Kurttio P, Salonen L. Determination of $^{234}U/^{238}U$ ratio: comparison of multi-collector ICPMS and ICP-QMS for water, hair and nails samples, and comparison with alpha-spectrometry for water samples. Radiation Protection Dosimetry **2006**; 118 (1): 106–110.

Karppinen J, Järvinen H. A practical method to the users of radiation for the the determination of patien doses in computed tomography. In: Book of Extended Synopses. IAEA-CN-146. International Conference on Quality Assurance and New Techniques in Radiation Medicine. 2006 Nov 13–15; Vienna, Austria. **2006a**. p. 26–27.

Karppinen J, Järvinen H. Optimization of the use of CT equipment. STUK-A220. Helsinki: Radiation and Nuclear Safety Authority; **2006b**. (In Finnish)

Karvonen P, Penttilä H, Äystö J, Billowes J, Campbell P, Elomaa V-V, Hager U, Hakala J, Jokinen A, Kessler T, Kankainen A, Moore ID, Peräjärvi K, Rahaman S, Rinta-Antila S, Rissanen J, Ronkainen J, Saastamoinen A, Sonoda T, Tordoff B, Weber C. Upgrade and yields of the IGISOL facility. Proceedings of the XV^{th} International Conference on Electromagnetic Isotope Separators and Techniques Related to their Applications. 2007 Jun 24–29; Deauville, France. Nuclear Instruments and Methods in Physics Research B **2008**; 266: 4454–4459.

Keikko T, Pääkkönen R, Kännälä S, Seesvuori R, Valkealahti S. Magnetic field risk evaluation of workers in indoor distribution substations. Paper 0182. In: CIRED – 20^{th} International Conference and Exhibition on Electricity Distribution. **2009** June 8–11; Prague, Czech Republic.

Keränen P, Arvela H. Radon resistant construction in Finland in 2007. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008:13. Østerås: Norwegian Radiation Protection Authority; **2008**. p. 125–129.

Kessler T, Moore ID, Kudryavtsev Y, Peräjärvi K, Popov A, Ronkanen P, Sonoda T, Tordoff B, Wendt KDA, Äystö J. Off-line studies of the laser ionization of yttrium at the IGISOL facility. Nuclear Instruments and Methods in Physics Research B **2008**; 266 (4): 681–700.

Keyriläinen J, Fernández M, Karjalainen-Lindsberg M-L, Virkkunen P, Leidenius M, von Smitten K, Sipilä P, Fiedler S, Suhonen S, Suortti P, Bravin A. Toward high-contrast breast CT at low radiation dose. Radiology **2008**; 249: 321–327.

Kiljunen T. Patient doses in CT, dental cone beam CT and projection radiography in Finland, with emphasis on paediatric patients. Academic dissertation. STUK-A232. Helsinki: Radiation and Nuclear Safety Authority; **2008**.

Kiljunen T, Järvinen H, Parviainen T, Komppa T, Savolainen S. Diagnostic reference levels for paediatric radiography in Finland. In: Valentin J, Cederlund T, Drake P, Finne IE, Glansholm A, Jaworska A, Paile W, Rahola T (Eds.). Radiological Protection in Transition – Proceedings of the XIV Regular Meeting of the Nordic Society for Radiation Protection, NSFS – Rättvik, Sweden, 27–31 August 2005. SSI Report 2005:15. Stockholm: Swedish Radiation Protection Authority; **2005**. p. 151–154.

Kiljunen T, Järvinen H, Parvianen T, Komppa T, Savolainen S. Patient doses and diagnostic reference levels in paediatric radiology in Finland: Phase I: The method. European Congress of Radiology (ECR 2006), 3–7 March 2006, Vienna, Austria. European Radiology **2006**; 16 Suppl 1: B256–257.

Kiljunen T, Järvinen H, Savolainen S. Diagnostic reference levels for thorax X-ray examinations of paediatric patients. The British Journal of Radiology **2007**; 80: 452–459.

Kiljunen T, Tietäväinen A, Parviainen T, Viitala A, Kortesniemi M. Organ doses and effective doses in pediatric radiography: Patient-dose survey in Finland. Acta Radiologica **2009**; 50 (1): 114–124.

Kinnunen T. Effects of structural, geological and climatic factors on indoor radon concentration of dwellings. Master's thesis. University of Jyväskylä, Department of Mathematics and Statistics; **2008**. (In Finnish)

Kiuru A, Lindholm C, Heilimo I, Ceppi M, Koivistoinen A, Ilus T, Hirvonen A, Norppa H, Salomaa S. Influence of DNA repair gene polymorphisms on the yield of chromosomal aberrations. Environmental and Molecular Mutagenesis **2005**; 46: 198–205.

Kiuru A, Lindholm C, Heinävaara S, Ilus T, Jokinen P, Haapasalo H, Salminen T, Collatz Christensen H, Feychting M, Johansen C, Lönn S, Malmer B, Schoemaker MJ, Swerdlow AJ, Auvinen A. XRCC1 and XRCC3 variants and risk of glioma and meningioma. Journal of Neuro-Oncology **2008**; 88 (2): 135–142.

Klaeboe L, Lönn S, Scheie D, Auvinen A, Christensen HC, Feychting M, Johansen C, Salminen T, Tynes T. Incidence of intracranial meningiomas in Denmark, Finland, Norway and Sweden, 1968–97. International Journal of Cancer **2005**; 117: 996–1001.

Klemola SK. Inter-laboratory comparisons of short-lived gamma-emitting radionuclides in nuclear reactor water. Applied Radiation and Isotopes **2008**; 66: 760–763.

Kojo K, Pukkala E, Auvinen A. Breast cancer risk among Finnish cabin attendants: a nested case-control study. Occupational & Environmental Medicine **2005**; 62 (7): 488–493.

Kojo K, Jansén CT, Nybom P, Huurto L, Laihia J, Ilus T, Auvinen A. Population exposure to ultraviolet radiation in Finland 1920–1995: exposure trends and a time series-analysis of exposure and cutaneous melanoma incidence. Environmental Research **2006**; 101 (1): 123–131.

Kojo K, Helminen M, Leuthold G, Aspholm R, Auvinen A. Estimating the cosmic radiation dose for a cabin crew with flight timetables. Journal of Occupational and Environmental Medicine **2007**; 49: 540–545.

Kojo K, Lahtinen T, Oikarinen A, Oivanen T, Artama M, Pastila R, Auvinen A. Reliability and validity of a bioimpedance measurement device in the assessment of UVR damage to the skin. Archives of Dermatological Research **2008**; 300: 253–261.

Korhonen K, Salminen T, Raitanen J, Auvinen A, Isola J, Haapasalo H. Female predominance in meningiomas can not be explained by differences in progesterone, estrogen or androgen receptor expression. Journal of Neuro-Oncology **2006**; 80 (1): 1–7.

Korhonen K, Raitanen J, Isola J, Haapasalo H, Salminen T, Auvinen A. Exogenous sex hormones use and risk of meningiomas – a population-based case–control study in Finland. Cancer Causes Control. Cancer Causes Control **2010**; 21 (12): 2149–2156.

Korhonen K, Auvinen A, Lyytinen H, Ylikorkala O, Pukkala E. A nation-wide study on meningioma incidence in women using postmenopausal hormone therapy in Finland. **Submitted** to American Journal of Epidemiology.

Korpela H, Niemelä J. Survey on quality control measurements for nuclear medicine imaging equipment in Finland in 2006. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008**. [CD-ROM, TS III.3.3: 675 (9 pp.)]

Korpela H, Bly R, Vassileva J, Ingilizova K, Stoyanova T, Kostadinova I, Slavchev A. Recently revised diagnostic reference levels in nuclear medicine in Bulgaria and in Finland. Radiation Protection Dosimetry **2010**; 139 (1–3): 317–320.

Kortesniemi M, Kiljunen T, Kangasmäki A. Radiation exposure in body computed tomography examinations of trauma patients. Physics in Medicine and Biology **2006**; 51: 3269–3282.

Kortesniemi M, Kiljunen T, Kangasmäki A. Radiation exposure in body computed tomography examinations of trauma patients. In: Vainio J, Pomoell J, Louhivuori M (Eds.). Proceedings of the XLI Annual Conference of the Finnish Physical Society. 2007 Mar 15–17; Tallinn, Estonia. Report series in physics. Helsinki: University of Helsinki; **2007**. p. 8.16.

Koskelainen M. Metal industry views in Finland on clearance and possible disposition alternatives. In: Proceedings of the International Conference on Control and Management of Inadvertent Radioactive Material in Scrap Metal. 2009 Feb 23–27; Tarragona, Spain. **2009a**

Koskelainen M. Metal industry concerns with disposition options for cleared radioactive scrap metal. In: Proceedings of the 6th International Symposium on Release of Radioactive Materials from Regulatory Requirements – Provisions for Exemption and Clearance. 2009 Sep 21–23; Wiesbaden, Germany. **2009b**

Koskelainen M. Comparison of current clearance standards and their brief history. In: Proceedings – Third European IRPA Congress, 14–18 June 2010, Helsinki, Finland. Helsinki: Nordic Society for Radiation Protection; **2011**. S18-02. p. 2662–2672.

Kostiainen E. Ecological half-lives of ^{137}Cs and ^{90}Sr in dairy milk in regions with different soil types. Radioprotection **2005a**; 40 Suppl 1: S391–S397.

Kostiainen ET. Variation in ^{137}Cs uptake of edible mushrooms. In: Strand P, Børretzen P, Jølle T (Eds). Proceedings from the 2nd International Conference on Radioactivity in the Environment. 2–6 October 2005, Nice, France. Østerås, Norway: Norwegian Radiation Protection Authority; **2005b**. p. 270–273.

Kostiainen E. ^{137}Cs in Finnish wild berries, mushrooms and game meat in 2000–2005. Boreal Environmental Research **2007**; 12: 23–28.

Kostiainen E. ^{137}Cs uptake of forest berries. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008:13. Østerås: Norwegian Radiation Protection Authority; **2008**. p. 135–140.

Kostiainen E, Ylipieti J. Radioactive cesium in Finnish edible mushrooms. STUK-A240. Helsinki: Radiation and Nuclear Safety Authority; **2010**. (In Finnish)

Kosunen A, Komppa T, Toivonen M. Evaluation of methods to estimate the patient dose in interventional radiology. Radiation Protection Dosimetry **2005**; 117 (1–3): 178–184.

Krajewski P, Ammann M, Bartusková M, Duffa C, Filistovic V, Homma T, Kanyár B, Malátová I, Nedveckaite T, Simon S, Vlasov O, Webbe-Wood D, Zvonova I. Validation of environmental transfer models and assessment of the effectiveness of countermeasures using data on ^{131}I releases from Chernobyl. Applied Radiation and Isotopes **2008**; 66: 1730–1735.

Kumlin T, Iivonen H, Miettinen P, Juvonen A, van Groen T, Puranen L, Pitkäaho R, Juutilainen J, Tanila H. Mobile phone radiation and the developing brain: Behavioral and morphological effects in juvenile rats. Radiation Research **2007**; 168: 471–479.

Kunseler E, Jantunen M, Arvela H. Assessment of information needs in Finnish indoor radon policy. Evaluation report. ENHIS: European Environment and Health Information System supporting policy making; **2007**.

Kurttio P, Komulainen H, Leino A, Salonen L, Auvinen A, Saha H. Komulainen H. Bone as a possible target of chemical toxicity of natural uranium in drinking water. Environmental Health Perspectives **2005**; 113 (1): 68–72.

Kurttio P, Harmoinen A, Saha H, Auvinen A, Karpas Z, Salonen L, Komulainen H. Kidney toxicity of ingested uranium from drinking water. American Journal of Kidney Diseases **2006a**; 47 (6): 972–982.

Kurttio P, Salonen L, Ilus T, Pekkanen J, Pukkala E, Auvinen A. Well water radioactivity and risk of cancers of the urinary organs. Environmental Research **2006b**; 102: 333–338.

Kurttio P, Pukkala E, Ilus T, Rahola T, Auvinen A. Global fallout and cancer incidence among reindeer herders and Sami in Northern Finland. Occupational and Environmental Medicine **2010**; 67: 737–743.

Kurvinen K, Smolander P, Pöllänen R, Kuukankorpi S, Kettunen M, Lyytinen J. Design of a radiation surveillance unit for an unmanned aerial vehicle. Journal of Environmental Radioactivity **2005**; 81: 1–10.

Kurvinen K, Smolander P, Pöllänen R, Lyytinen J, Kettunen M. Radiation surveillance using an unmanned aerial vehicle Ranger. MATINE Series A, 2008/2. Helsinki: Ministry of Defence: Scientific Advisory Board for Defence MATINE; **2008**. (In Finnish)

Kuukankorpi S, Toivonen H, Moring M, Smolander P. Mobile spectrometry for source finding and prompt reporting. STUK-A224. Helsinki: Radiation and Nuclear Safety Authority; **2007**.

Kwon M-S, Jääskeläinen SK, Toivo T, Hämäläinen H. No effects of mobile phone electromagnetic field on auditory brainstem response. Bioelectromagnetics **2010**; 31 (1): 48–55.

Kwon MS, Vorobyev V, Kännälä S, Laine M, Rinne J, Toivonen T, Johansson J, Teräs M, Joutsa J, Tuominen L, Lindholm H, Alanko T, Hämäläinen H. No effects of short-term GSM mobile phone radiation on cerebral blood flow as measured by positron emission tomography. Bioelectromagnetics. **In Press**

Kwon MS, Vorobyev V, Kännälä S, Laine M, Rinne J, Toivonen T, Johansson J, Teräs M, Lindholm H, Alanko T, Hämäläinen H. GSM mobile phone radiation suppresses brain glucose metabolism. Journal of Cerebral Blood Flow & Metabolism. **In Press**

Kännälä S, Puranen L, Sihvonen A-P, Jokela K. Measured and computed induced body currents in front of an experimental RF dielectric heater. Health Physics **2008**; 94 (2):161–169.

Kännälä S, Toivo T, Alanko T, Jokela K. Occupational exposure measurements of static and pulsed gradient magnetic fields in the vicinity of MRI scanners. Physics in Medicine and Biology **2009**; 54: 2243–2257.

Lahkola A. Mobile phone use and risk of brain tumours. Academic dissertation. STUK-A246. Helsinki: Radiation and Nuclear Safety Authority; **2010**.

Lahkola A, Salminen T, Auvinen A. Selection bias due to differential participation in a case-control study of mobile phone use and brain tumors. Annals of Epidemiology **2005**; 15: 321–325.

Lahkola A, Tokola K, Auvinen A. Meta-analysis of mobile phone use and intracranial tumors. Scandinavian Journal of Work, Environment & Health **2006**; 32 (2): 171–177.

Lahkola A, Auvinen A, Raitanen J, Schoemaker MJ, Collatz Christensen H, Feychting M, Johansen C, Klæboe L, Lönn S, Swerdlow AJ, Tynes T, Salminen T. Mobile phone use and risk of glioma in five North European countries. International Journal of Cancer **2007**; 120: 1769–1775.

Lahkola A, Salminen T, Raitanen J, Heinävaara S, Schoemaker MJ, Collatz Christensen H, Feychting M, Johansen C, Klæboe L, Lönn S, Swerdlow AJ, Tynes T, Auvinen A. Meningioma and mobile phone use – an international collaborative case-control study in five North European countries. International Journal of Epidemiology **2008**; 37 (6): 1304–1313.

Lahtinen J, Toivonen H, Hänninen R. Effective use of radiation monitoring data and dispersion calculations in an emergency. International Journal of Emergency Management **2007**; 4 (3): 468–480.

Lahtinen J, Aage H K, Ammann M, Dyve J E, Hoe S, Rojas-Palma C, Wirth E. Guidance on monitoring and data assimilation. Radioprotection **2010**; 45 (5): S161–S169.

Laine AO, Mattila J, Lehikoinen A. First record of the brackish water dreissenid bivalve *Mytilopsis leucophaeata* in the northern Baltic Sea. Aquatic Invasions **2006**; 1: 38–41.

Larjavaara S, Mäntylä R, Salminen T, Haapasalo H, Raitanen J, Jääskeläinen J, Auvinen A. Incidence of gliomas by anatomic location. Neuro-Oncology **2007**; 9: 319–325.

Larjavaara S, Haapasalo H, Sankila R, Helén P, Auvinen A. Is the incidence of meningiomas underestimated? A regional survey. Short Communication. British Journal of Cancer **2008**; 99:182–184.

Larjavaara S, Schüz J, Swerdlow A, Feychting M, Johansen C, Lagorio S, Tynes T, Klaeboe L, Tonjer SR, Blettner M, Berg-Beckhoff G, Schlehofer B, Schoemaker M, Britton J, Mäntylä R, Lönn S, Ahlbom A, Flodmark O, Lilja A, Martini S, Rastelli E, Vidiri A, Kähärä V, Raitanen J, Heinävaara S, Auvinen A. Location of gliomas in relation to mobile telephone use: a case-case and case-specular analysis. Epub 2011 May 24. American Journal of Epidemiology **2011**; 174 (1). (10 pp.)

Larjavaara S, Feychting M, Sankila R, Johansen C, Klaeboe L, Schüz J, Auvinen A. Incidence trends of vestibular schwannomas in Denmark, Finland, Norway and Sweden in 1987–2007. **Submitted** to British Journal of Cancer.

Lehtinen M, Havukainen R. The national dose register in Finland. Radiation Protection Dosimetry **2011**; 144 (1–4): 72–75.

Lehtinen M, Ansaranta T, Havukainen R. Trends and dose distributions for occupational radiation exposure in Finland. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008**. [CD-ROM, TS II.2.3: 655 (10 pp.)]

Leppänen A, Grinsted A. Observations of cosmogenic ^{7}Be and ^{22}Na in aerosol samples in Northern Finland. Natural Radiation Environment VIII Conference. **2007** Oct 7–12; Buzios, Brasilia.

Leppänen A, Grinsted A. Observations of cosmogenic ^{7}Be and ^{22}Na in aerosol samples in Northern Finland. In: Proceedings of the 8th International Symposium on the Natural Radiation Environment (NRE-VIII). 2007 Oct 7–12; Búzios, Brazil. New York: The American Institute of Physics (AIP); **2008**. p. 112–115.

Leppänen A, Solatie D. Monitoring and studying radioactivity in the Northern Finland and in the Arctic. In: Kauranen M, Laitinen A, Nieminen J, Rantala T (Eds.). Proceedings of the XL Annual Conference of the Finnish Physical Society, March 9–11 2006, Tampere, Finland: Tampere University of Technology, Institute of Physics. Report **2006**:1. p. 156.

Leppänen A-P, Uusitalo J, Greenlees PT, Herzberg R-D, Amzal N, Becker F, Butler PA, Chewter AJC, Cocks JFC, Dorvaux O, Eeckhaudt S, Eskola K, Gerl J, Grahn T, Hammond NJ, Hauschild K, Helariutta K, Heβberger FP, Houry M, Jones GD, Jones PM, Julin R, Juutinen S, Kankaanpää H, Kettunen H, Khoo TL, Korten W, Kuusiniemi P, Le Coz Y, Leino M, Lister CJ, Lucas R, Muikku M, Nieminen P, Nyman M, Page RD, Pakarinen J, Rahkila P, Reiter P, Sarén J, Schlegel Ch, Scholey C, Stezowski O, Theisen Ch, Trzaska WH, Wollersheim HJ. Recoil-fission tagging of the transfermium nucleus ^{252}No. The European Physical Journal **2006**; A (28): 301–306.

Leppänen A-P, Pacini AA, Usoskin IG, Aldahan A, Echer E, Evangelista H, Klemola S, Kovaltsov GA, Mursula K, Possnert G. Cosmogenic ^{7}Be in air: A complex mixture of production and transport. Journal of Atmospheric and Solar-Terrestrial Physics **2010**; 72: 1036–1043.

Leppänen A-P, Muikku M, Jaakkola T, Lehto J, Rahola T, Rissanen K, Tillander M. Effective half-lives of ^{134}Cs and ^{137}Cs in reindeer meat and in reindeer herders in Finland after the Chernobyl accident, and the ensuing effective radiation doses to humans. Health Physics **2011**; 100 (5): 468–481.

Leppänen A-P, Kasatkina N, Gennady M, Solatie D, Vaaramaa, K. Radioecological studies in the Barents Sea. **Submitted** to Journal of Environmental Radioactivity.

Leppänen A-P, Usoskin IG, Kovaltsov GA, Paatero J. Cosmogenic ^{7}Be and ^{22}Na concentrations in surface air in Finland: Seasonal and interannual variations. **Submitted** to Journal of Atmospheric and Solar-Terrestrial Physics.

Lépy M-C, Altzitzoglou T, Anagnostakis M J, Arnold D, Capogni M, Ceccatelli A, De Felice P, Dersch R, Dryak P, Fazio A, Ferreux L, Guardati M, Han J B, Hurtado S, Karfopoulos K L, Klemola S, Kovar P, Lee K B, Ocone R, Ott O, Sima O, Sudar S, Švek A, Chau Van Tao, Tran Thien Thanh, Vidmar T. Intercomparison of methods for coincidence summing corrections in gamma-ray spectrometry. Applied Radiation and Isotopes **2010**; 68: 1407–1412.

Leszczynski D. Activation of cellular stress response by RF-EMF and its possible impact on cell physiology. Proceedings of the 28th Assembly of URSI, New Delhi, India, 23.–29.10.2005. File K02.7-01576. **2005a**

Leszczynski D. Overview of the present status and future directions of research into biological effects of EMF using high-throughput screening techniques. Proceedings of the 28th Assembly of URSI, New Delhi, India, 23.–29.10.2005. File K03.1-01199. **2005b**

Leszczynski D. Rapporteur report: Cellular, animal and epidemiological studies of the effects of static magnetic fields relevant to human health. Biophysics and Molecular Biology **2005c**; 87: 247–253.

Leszczynski D. The need for a new approach in studies of the biological effects of electromagnetic fields. Editorial. Proteomics **2006**; 6 (17): 4671–4673.

Leszczynski D. Mobile phone radiation and gene expression. Letter to Editor. Radiation Research **2007**; 167: 121.

Leszczynski D. How reliable is the science behind safety standards for mobile phones? In: Proceedings of the 6th International Workshop on Biological Effects of EMF. **2010** Oct 10–15; Bodrum, Turkey. [CD-ROM]

Leszczynski D, Meltz ML. Questions and answers concerning applicability of proteomics and transcriptomics in EMF research. Report. Proteomics **2006**; 6 (17): 4674–4677.

Leszczynski D, Xu Z. Commentary: Mobile phone radiation health risk controversy: the reliability and sufficiency of science behind the safety standards. Health Research Policy and Systems **2010**; 8 (1): 2. (6 pp.)

Li C, Pastila R, Pitsillides C, Runnels JM, Puoris'haag M, Cote D, and Lin CP. Imaging leukocyte trafficking in vivo with two-photon-excited endogenous tryptophan fluorescence. Optics Express **2010**; 18 (2): 988–999.

Li WB, Salonen L, Muikku M, Wahl W, Höllriegl V, Oeh U, Roth P, Rahola T. Internal dose assessment of natural uranium from srinking water based on biokinetic modeling and individual bioassay monitoring: A study of a Finnish family. Health Physics **2006**; 90 (6): 533–543.

Li WB, Karpas Z, Salonen L, Kurttio P, Muikku M, Wahl W, Höllriegl, Hoeschen C, Oeh U. A compartmental model of uranium in human hair for protracted ingestion of natural uranium in drinking water. Health Physics **2009**; 96 (6): 636–645.

Lindholm C, Jaworska A, Stricklin D. Nordic collaboration within biological dosimetry. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008: 13. Østerås: Norwegian Radiation Protection Authority; **2008**. p. 89–94.

Lindholm C, Acheva A, Salomaa S. Clastogenic plasma factors: a short overview. Radiation and Environmental Biophysics **2010a**; 49 (2): 133–138.

Lindholm C, Stricklin D, Jaworska A, Koivistoinen A, Paile W, Arwidsson E, Deperas-Standylo J, Wojcik A. Premature chromosome condensation (PCC) assay for dose assessment in mass casualty accidents. Radiation Research **2010b**; 173 (1): 71–78.

Lipping T, Rorarius M, Jäntti V, Annala K, Mennander A, Ferenets R, Toivonen T, Toivo T, Värri A, Korpinen L. Using the nonlinear control of anaesthesia-induced hypersensitivity of EEG at burst suppression level to test the effects of radiofrequency radiation on brain function. Nonlinear Biomedical Physics **2009**; 3: 5. (10 pp.)

Little MP, Filipe JAN, Prise KM, Folkard M, Belyakov OV. A model for radiation-induced bystander effects, with allowance for spatial position and the effects of cell turnover. Journal of Theoretical Biology **2005**; 232 (3): 329–338.

Lopez MA, Etherington G, Castellani CM, Franck D, Hurtgen C, Marsh JW, Nosske D, Doerfel H, Andrasi A, Bailey M, Balashazy I, Battisti P. Bérard P, Berkowski V, Birchall A, Blanchardon E, Bonchuk Y, de Carlan L, Cantone MC, Challeton-de Vathaire, Cruz-Suarez R, Davis K, Dorrian D, Giussani A, Le Guen B, Hodgson A, Jourdain JR, Koukouliou V, Luciani A, Malatova I, Molokanov A, Moraleda M, Muikku M, Oeh U, Puncher M, Rahola T, Ratia H, Stradling N. Coordination of research on internal dosimetry in Europe: the Conrad project. Radiation Protection Dosimetry **2007**; 127 (1–4): 311–316.

Lopez MA, Etherington G, Castellani CM, Franck D, Hurtgen C, Marsh JW, Nosske D, Breustedt B, Blanchardon E, Andrasi A, Bailey M.R, Balashazy I, Battisti P, Bérard P, Birchall A, Broggio D, Challeton-de-Vathaire C, Cruz-Suarez R, Doerfel H, Giussani A, Hodgson A, Koukouliou V, Kramer GH, Le Guen B, Luciani A, Malatova I, Molokanov A, Moraleda M, Muikku M, Oeh U, Puncher M, Rahola T, Stradling N, Vrba T. Internal dosimetry: Towards harmonisation and coordination of research. Radiation Protection Dosimetry **2008**; 131 (1): 28–33.

Lucenius J. Variation of beryllium-7 and lead-210 concentrations in atmosphere of Lapland during the summer 2008. Bachelor's Thesis. University of Helsinki, Department of Physics; 2008. (In Finnish)

Lüning M, Ilus E, Herrmann J. Sources of radioactive substances in the Baltic Sea. In: Radioactivity in the Baltic Sea 1999–2006. HELCOM thematic assessment. Baltic Sea Environment Proceedings No. 117. Helsinki: HELCOM (Helsinki Comission, Baltic Marine Environment Protection Commission); **2009**. p. 9–17.

Malisan MR, Padovani R, Faulkner K, Malone JF, Vano, Jankowski J, Kosunen A. Proposal for patient database on cardiac interventional exposures for epidemiological studies. Radiation Protection Dosimetry **2008**; 129 (1–3): 96–99.

Malmer BS, Feychting M, Lönn S, Lindström S, Grönberg H, Ahlbom A, Schwartzbaum J, Auvinen A, Collatz-Christensen H, Johansen C, Kiuru A, Mudie N, Salminen T, Schoemaker MJ, Swerdlow AJ, Henriksson R. Genetic variation in p53 and ATM haplotypes and risk of glioma and meningioma. Journal of Neuro-Oncology **2007**; 82: 229–237.

Manninen P, Hovila J, Seppälä L, Kärhä P, Ylianttila L, Ikonen E. Determination of distance offsets of diffusers for accurate radiometric measurements. Metrologia **2006**; 43 (2): 120–124.

Manninen P, Koskela T, Ylianttila L, Kärhä P, Ikonen E. Estimation of the optical receiving plane positions of solar spectroradiometers with spherical diffusers on the basis of spatial responsivity data. Optics Letters **2009**; 34 (20): 3241–3243.

Markkanen M. Technical guidance on safe installation of a GAC filter used for removing radon from water. Proceedings of Seventh International Symposium on the Natural Radiation Environment (NRE-VII), Rhodes, Greece, 20–24 May 2002. In: Baxter MS (Ed.).Radioactivity in the Environment. Volume 7. Oxford: Elsevier Ltd.; **2005**. p. 665–669.

Matishov GG, Matishov DG, Solatie D, Kasatkina N, Leppänen A. Natural deacrease of the intensity level of artificial radioactive isotopes in the Barents Sea. Oceanology **2009**; 427A (6): 1006–1011.

Mattila J, Ilus E. Radionuclides in sediments. In: Radioactivity in the Baltic Sea 1999–2006. HELCOM thematic assessment. Baltic Sea Environment Proceedings No. 117. Helsinki: HELCOM (Helsinki Comission, Baltic Marine Environment Protection Commission); **2009**. p. 25–29.

Mattila J, Kankaanpää H, Ilus E. Estimation of recent sediment accumulation rates in the Baltic Sea using artificial radionuclides ^{137}Cs and $^{239,240}Pu$ as time markers. Boreal Environmental Research **2006a**; 11: 95–107.

Mattila J, Kankaanpää H, Ilus E. Use of ^{137}Cs, $^{239,240}Pu$ and ^{210}Pb in sediment accumulation studies in the Baltic Sea. In: Isotopes in Environmental Studies. Aquatic Forum 2004. Proceedings of an international conference held in Monaco, 25–29 October 2004. Conference & Symposium Papers 26/P. Vienna: IAEA; **2006b**. p. 405–408.

Meinander O, Kazadzis S, Blumthaler M, Ylianttila L, Johnsen B, Lakkala K, Koskela T, Josefsson W. Diurnal discrepancies in spectral solar UV radiation measurements. Applied Optics **2006**; 45 (21): 5346–5357.

Meinander O, Kontu A, Lakkala K, Heikkilä A, Ylianttila L, Toikka M. Diurnal variations in the UV albedo of arctic snow. Atmospheric Chemistry and Physics **2008**; 8 (21): 6551–6543.

Menetrier F, Berard Ph, Joussineau S, Morcillo M-A, Cebrian D, List V, Hodgson A, Stradling N, Paile W, Holt DCB, Eriksson T, Holmlund J-A. Dose assessment of inhaled radionuclides in an emergency situation. Chilton: Health Protection Agency; **2007a**.

Ménétrier F, Bérard Ph, Joussineau S, Stradling N, Hodgson A, List V, Morcillo MA, Paile W, Holt DCB, Eriksson T. TIARA: Treatment Initiatives after Radiological Accidents. Radiation Protection Dosimetry **2007b**; 127 (1–4): 444–448.

Merimaa K, Järvinen H, Kortesniemi M, Karppinen J. A direct method for air kerma–length product measurement in CT for verification of dose display calibrations. Radiation Protection Dosimetry **2010**; 140 (3): 274–280.

Metso S, Auvinen A, Huhtala H, Salmi J, Oksala H, Jaatinen P. Increased cancer incidence following radioiodine treatment for hyperthyroidism. Cancer **2007a**; 109 (10): 1972–1979.

Metso S, Jaatinen P, Huhtala H, Auvinen A, Oksala H, Salmi J. Increased cardiovascular and cancer mortality after radioiodine treatment for hyperthyroidism. The Journal of Clinical Endocrinology & Metabolism **2007b**; 92 (6): 2190–2196.

Metso S, Auvinen A, Salmi J, Huhtala H, Jaatinen P. Increased long-term cardiovascular morbidity among patients treated with radioactive iodine for hyperthyroism. Clinical Endocrinology **2008**; 68: 450–457.

Metsäranta H, Kekonen T, Junttila M, Solatie D, Ikäheimonen TK. Strontium and Cesium deviation in snow after a radioactive fallout. **Submitted** to Journal of Environmental Radioactivity.

Moore ID, Kessler T, Sonoda T, Kudryavtsev Y, Peräjärvi K, Popov A, Wendt KDA, Äystö J. A study of on-line gas cell processes at IGISOL. Nuclear Instruments and Methods in Physics Research B **2010**; 268: 657–670.

Mrena S, Kivelä T, Kurttio P, Auvinen A. Lens opacities among physicians occupationally exposed to ionizing radiation – a pilot study in Finland. Scandinavian Journal of Work, Environment and Health **2011**; 37 (3): 237–243.

Muikku M, Rahola T. Improvement of the measuring equipment used in the assessment of internal doses in emergency situations. Radiation Protection Dosimetry **2007**; 127 (1–4): 277–281.

Muikku M, Arvela H, Järvinen H, Korpela H, Kostiainen E, Mäkeläinen I, Vartiainen E, Vesterbacka K. The mean effective dose for Finns – Review 2004. STUK-A211. Helsinki: Radiation and Nuclear Safety Authority; **2005**. (In Finnish)

Muikku M, Heikkinen T, Puhakainen M, Rahola T, Salonen L. Assessment of occupational exposure to uranium by indirect methods needs information on natural background variations. Radiation Protection Dosimetry **2007**; 125 (1–4): 492–495.

Muikku M, Huikari J, Pusa S. A New mobile whole-body counter for measurement of internal contamination in Finland. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008:13. Østerås: Norwegian Radiation Protection Authority; **2008**. p. 225–229.

Muikku M, Puhakainen M, Heikkinen T, Ilus T. The mean concentration of uranium in drinking water, urine, and hair of the occupationally unexposed Finnish working population. Health Physics **2009**; 96 (6): 646–654.

Mussalo-Rauhamaa H, Paile W, Tuomisto J, Vuorinen HS (Eds.). Environmental health. Helsinki: Duodecim Medical Publications Ltd; **2007**. (In Finnish)

Mustajoki J, Hämäläinen RP, Sinkko K. Interactive computer support in decision conferencing: Two cases on off-site nuclear emergency management. Decision Support Systems **2007**; 42: 2247–2260.

Mustonen R. Chapter 1. Potential sources of contamination in inhabited areas. In: Andersson KG (Ed.). Radioactivity in the Environment 2009, volume15: Airborne Radioactive Contamination in Inhabited Areas. The Netherlands: Elsevier; **2009**. p. 1–20.

Mustonen R, Ikäheimonen TK. Science and regulation 50 years hand in hand in radiation safety work in Finland. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008**. [CD-ROM, TS II.1.2: 3276 (9 pp.)]

Mustonen R, Sinkko K, Hämäläinen RP. Facilitated workshop method to involve stakeholders and public in decision-making process in radiological emergencies. In: Andersson K (Ed.). Value in decisions on risk – Proceedings (May 14–18, 2006). Stockholm: Congrex Sweden; **2006**. p. 538–545.

Mustonen R, Sjöblom K-L, Bly R, Havukainen R, Ikäheimonen TK, Kosunen A, Markkanen M, Paile W. Radiation protection recommendations 2007 – The Finnish translation of the publication ICRP 103. STUK-A235. Helsinki: Radiation and Nuclear Safety Authority; **2009**. (In Finnish)

Mäkeläinen I. Radon. Chapter in book: Mussalo-Rauhamaa H, Paile W, Tuomisto J, Vuorinen HS (Eds.). Environmental health. Helsinki: Duodecim Medical Publications Ltd; **2007**. p. 105–114. (In Finnish)

Mäkeläinen I, Moisio S, Reisbacka H, Turtiainen T. Indoor occupancy and radon exposure in Finland. In: McLaughlin JP, Simopoulos SE, Steinhäusler F (Eds). Radioactivity in the environment. Elsevier **2005**; 7: 687–693.

Mäkeläinen I, Kinnunen T, Reisbacka H, Valmari T, Arvela H. Radon in Finnish dwellings – Sample survey 2006. STUK-A242. Helsinki: Radiation and Nuclear Safety Authority; **2009**. (In Finnish)

Mäkeläinen I, Valmari T, Reisbacka H, Kinnunen T, Arvela H. Indoor radon and construction practices in Finnish homes from the 20th to the 21st century. In: Proceedings – Third European IRPA Congress, 14–18 June 2010, Helsinki, Finland. Helsinki: Nordic Society for Radiation Protection; **2011**. S03-11. p. 561–569.

Mäkinen I, Hanste U-M. Proficiency testing for measurement of radon (^{222}Rn) in drinking water. Accreditation and Quality Assurance **2009**; 14: 473–476.

Mäntyniemi K. Determination of ^{137}Cs activity concentration in live reindeers. Master's Thesis. University of Jyväskylä, Department of Physics; **2007**. (In Finnish)

Nielsen SP, Lüning M, Ilus E, Outola I, Ikäheimonen T, Mattila J, Herrmann J, Kanisch G, Osvath I. Baltic Sea. In: Atwood DA (Ed.). Radionuclides in the Environment. Wiley; **2010**.

Nieminen K. Calibration of the ionization chamber used in CT dosimetry. Master's Thesis. University of Helsinki, Faculty of Science, Department of Physical Sciences, **2006**. (In Finnish)

Niittymäki H, Hakanen A, Rautio S, Järvinen H. Portable TL dosemeter – ESD phantom combination for chest and lumbar spine radiography. Radiation Protection Dosimetry **2008**; 130: 224–227.

Nisbet AF, Mercer JA, Rantavaara A, Hänninen R, Vandecasteele C, Carlé B, Hardeman F, Ioannides KG, Papachristodoulou C, Tzialla C, Ollagnon H, Jullien T, Pupin V. Achievements, difficulties and future challenges for the FARMING network. Journal of Environmental Radioactivity **2005a**; 83: 263–274.

Nisbet AF, Mercer JA, Rantavaara A, Hänninen R, Vandecasteele C, Hardeman F, Ioannides KG, Tzialla C, Ollagnon H, Pupin V, Jullien T. Variation in stakeholder opinion on countermeasures across Europe. Journal of Environmental Radioactivity **2005b**; 83: 371–381.

Nisbet AF, Brown J, Howard BJ, Beresford NA, Ollagnon H, Turcanu C, Camps J, Andersson K, Rantavaara A, Ikäheimonen T, Duranova T, Oughton D, Kirchner G, Papachristodoulou C, Ioannides K, Kwakman P. Decision aiding handbooks for managing contaminated food production systems, drinking water and inhabited areas in Europe. Radioprotection **2010**; 45 (5): S23–S37.

Nishizawa K, Yoshinaga S, Karppinen J, Vehmas T. Radiation exposure and risk assessment in HRCT. In: Kusaka Y, Hering KG, Parker JE (Eds.). International classification of HRCT for occupational and Environmental respiratory diseases. Tokyo: Springer-Verlag; **2005**.

Norppa H, Bonassi S, Hansteen I-L, Hagmar L, Strömberg U, Rössner P, Boffetta B, Lindholm C, Gundy S, Lazutka J, Cebulska-Wasilewska A, Fabiánová E, Šrám RJ, Knudsen LE, Barale R, Fucic A. Chromosomal aberrations and SCEs as biomarkers of cancer risk. Mutation Research **2006**; 600: 37–45.

Nylund R, Leszczynski D. Mobile phone radiation causes changes in gene and protein expression in human endothelial cell lines and the response seems to be genome- and proteome-dependent. Proteomics **2006**; 6 (17): 4769–4780.

Nylund R, Tammio H, Kuster N, Leszczynski D. Proteomic analysis of the response of human endothelial cell line EA.hy926 to 1800 GSM mobile phone radiation. Journal of Proteomics and Bioinformatics **2009**; 2 (10): 455–462.

Nylund R, Kuster N, Leszczynski D. Analysis of proteome response to the mobile phone radiation in two types of human primary endothelial cells. Proteome Science **2010**; 8 (1): 52. (7 pp.)

O’Connor U, Dowling A, Larkin A, Sheahan N, Gray L, Gallagher A, O’Reilly G, Kosunen A, Zdesar U, Malone JF. Development of training syllabi for radiation protection and quality assurance of dual-energy x-ray absorptiometry (DXA) systems. Radiation Protection Dosimetry **2008**; 129 (1–3): 211–213.

OECD. Scientific issues and emerging challenges for radiological protection. Report of the expert group on the implications of radiological protection science. (Expert group: Ahier B, Bourguignon M, Bouville A, Bréchignac F, Brownless G, Doi M, Flury-Hérard A, Kelly GN, Lazo T, Métivier H, Mitchel R, Mossman K, Paquet F, Priest N, Salomaa S, Vano E, Vrijheid M, Weiss W, Zankl M.) NEA No. 6167. France: OECD; **2007**.

Oivanen T, Kojo K, Pylkkänen L, Holli K, Auvinen A. Early detection of skin cancer as public health policy: Comparison of campaign and routine activity. Preventive Medicine **2008**; 46 (2): 160–165.

Oksanen M, Niemistö H, Saxén R. Estimation of radiation doses from ^{137}Cs to perch in a Finnish lake. In: Protection of the environment from the effects of ionizing radiation. Contributed papers of an international conference, Stockholm, 6–10 October 2003. STI/PUB/1229 Companion CD. Vienna: International Atomic Energy Agency; **2005**. p. 205–207. [CD-ROM]

Outola I, Filliben J, Inn KGW, La Rosa J, McMahon CA, Peck GA, Twining J, Tims SG, Fifield LK, Smedley P, Antón MP, Gascó C, Povinec P, Pham MK, Raaum A, Wei H-J, Krijger GC, Bouisset P, Litherland AE, Kieser WE, Betti M, Aldave de las Heras L, Hong GH, Holm E, Skipperud L, Harms AV, Arinc A, Youngman M, Arnold D, Wershofen H, Sill D S, Bohrer S, Dahlgaard H, Croudace I W, Warwick PE, Ikäheimonen TK, Klemola S, Vakulovsky SM, Sanchez-Cabeza JA. Characterization of the NIST seaweed Standard Reference Material. Applied Radiation and Isotopes **2006**; 64: 1242–1247.

Outola I, Inn K, Ford R, Markham S, Outola P. Optimizing standard sequential extraction protocol with lake and ocean sediments. Journal of Radioanalytical and Nuclear Chemistry **2009a**; 282: 321–327.

Outola I, Saxén R, Heinävaara S. Transfer of ^{90}Sr into fish in Finnish lakes. Journal of Environmental Radioactivity **2009b**; 100 (8): 657–664.

Paatero J, Kulmala S, Jaakkola T, Saxén R, Buyukay M. Deposition of ^{125}Sb, ^{106}Ru, ^{144}Ce, ^{134}Cs and ^{137}Cs in Finland after the Chernobyl accident. Boreal Environmental Research **2007**; 12: 43–54.

Paatero J, Vesterbacka K, Makkonen U, Kyllönen K, Hellen H, Hatakka J, Anttila P. Resuspension of radionuclides into the atmosphere due to forest fires. Journal of Radioanalytical and Nuclear Chemistry **2009**; 282: 473–476.

Paatero J, Hämeri K, Jaakkola T, Jantunen M, Koivukoski J, Saxén R. Airborne and deposited radioactivity from the Chernobyl accident – a review of investigations in Finland. Boreal Environment Research **2010a**; 15: 19–33.

Paatero J, Saxén R, Buyukay M, Outola I. Overview of strontium-89,90 deposition measurements in Finland 1963–2005. Journal of Environmental Radioactivity **2010b**; 101: 309–316.

Paile W. A guide on radiation accidents for the general practitioner. Health Physics **2010**; 98 (6): 788–789.

Parviainen T. Staff doses in cardiological interventional radiography. Master's Thesis. University of Kuopio, **2008**.

Pastila R. Effect of long-wave UV radiation on mouse melanoma: An in vitro and in vivo study. Academic dissertation. STUK-A216. Helsinki: Radiation and Nuclear Safety Authority; **2006**.

Pastila R (Ed.). Ultraviolet and laser radiation. Radiation and Nuclear Safety Series, Part 7. Helsinki: Radiation and Nuclear Safety Authority; **2009**. (In Finnish)

Pastila R, Leszczynski D. Ultraviolet A exposure alters adhesive properties of mouse melanoma cells. Photodermatology, Photoimmunology & Photomedicine **2005a**; 21: 183–190.

Pastila R, Leszczynski D. Ultraviolet A exposure might increase metastasis of mouse melanoma: a pilot study. Photodermatology, Photoimmunology & Photomedicine **2005b**; 21: 234–241.

Pastila R, Leszczynski D. Ultraviolet-A radiation induces changes in cyclin G gene expression \r\nin mouse melanoma B16-F1 cells. Cancer Cell International **2007**; 7: 7. (9 pp.)

Pastila R, Heinävaara S, Ylianttila L, Leszczynski D. *In vivo* UVA irradiation of mouse is more efficient in promoting pulmonary melanoma metastasis than *in vitro*. Epub 2006 June 11. Cancer Cell International **2011**; 11: 16. (8 pp.)

Peltonen T, Ammann M, Lahtinen J, Vesterbacka K. Operational experience with the Ketale Web application. In: French S, Romaszewski B, Zobel C (Eds.). Proceedings of the 7th International Conference on Information Systems for Crisis Response and Management. Defining Crisis Management 3.0. May **2010**, Seattle, USA.

Penttilä H, Karvonen P, Eronen T, Äystö J, Elomaa V-V, Hager U, Hakala J, Jokinen A, Kankainen A, Moore ID, Peräjärvi K, Rahaman S, Rinta-Antila S, Rubchenya V, Sonoda T. Determining independent fission product yields with a Penning trap. European Physical Journal A **2010**; 44 (1); 147–168.

Peräjärvi K, Lehtinen J, Pöllänen R, Toivonen H. Design of an air sampler for a small unmanned aerial vehicle. Radiation Protection Dosimetry **2008a**; 132 (3): 328–333.

Peräjärvi K, Turunen J, Hakala J, Jokinen A, Moore ID, Penttilä H, Saastamoinen A, Siiskonen T, Toivonen H, Äystö J. The decay of ^{133m}Xe. Applied Radiation and Isotopes **2008b**; 66 (4): 530–534.

Peräjärvi K, Hakala J, Jokinen A, Moore ID, Penttilä H, Pöllänen R, Saastamoinen A, Toivonen H, Turunen J, Äystö J. Event mode data acquisition for characterization of samples containing radioactive particles. IEEE Transactions on Nuclear Science **2009**; 56 (3): 1444–1447.

Peräjärvi K, Eronen T, Elomaa V-V, Hakala J, Jokinen A, Kettunen H, Kolhinen VS, Laitinen M, Moore ID, Penttilä H, Rissanen J, Saastamoinen A, Toivonen H, Turunen J, Äystö J. Ultra-high resolution mass separator – Application to detection of nuclear weapons tests. Applied Radiation and Isotopes **2010**; 68: 450–453.

Peräjärvi KA, Ihantola S, Pöllänen RC, Toivonen HI, Turunen JA. Determination of ^{235}U, ^{239}Pu, ^{240}Pu, and ^{241}Am in a nuclear bomb particle using a position-sensitive α-γ coincidence technique. Environmental Science and Technology **2011**; 45 (4): 1528–1533.

Peräjärvi K, Eronen T, Gorelov D, Hakala J, Jokinen A, Kettunen H, Kolhinen V, Laitinen M, Moore ID, Penttilä H, Rissanen J, Saastamoinen A, Toivonen H, Turunen J, Äystö J. Production of pure ^{133m}Xe for CTBTO. **Submitted** to Hyperfine Interactions.

Pham MK, Sanchez-Cabeza JA, Povinec PP, Andor K, Arnold D, Benmansour M, Bikit I, Carvalho FP, Dimitrova K, Edrev ZH, Engeler C, Fouche FJ, Garcia-Orellana J, Gascó C, Gastaud J, Gudelis A, Hancock G, Holm E, Legarda F, Ikäheimonen TK, Ilchmann C, Jenkinson AV, Kanisch G, Kis-Benedek G, Kleinschmidt R, Koukouliou V, Kuhar B, LaRosa J, Lee S-H, LePetit G, Levy-Palomo Ia, Liong Wee Kwong L, Llauradó M, Maringer FJ, Meyer M, Michalik B, Michel H, Nies H, Nour S, Oh J-S, Oregioni B, Palomares J, Pantelic G, Pfitzner J, Pilvio R, Puskeiler L, Satake H, Schikowski J, Vitorovic G, Woodhead D, Wyse E. A new Certified Reference Material for radionuclides in Irish sea sediment (IAEA-385). Applied Radiation and Isotopes **2008**; 66: 1711– 1717.

Pham MK, Betti M, Povinec PP, Benmansour M, Bünger V, Drefvelin J, Engeler C, Flemal JM, Gascó C, Guillevic J, Gurriaran R, Groening M, Happel JD, Herrmann J, Klemola S, Kloster M, Kanisch G, Leonard K, Long S, Nielsen S, Oh J-S, Rieth PU, Östergren I, Pettersson H, Pinhao N, Pujol L, Sato K, Schikowski J, Varga Z, Vartti VP, Zheng J. A certified reference material for radionuclides in the water sample from Irish Sea (IAEA-443). Journal of Radioanalytical and Nuclear Chemistry **2011**; 288: 603 – 611.

Pluder F, Barjaktarovic Z, Azimzadeh O, Mörtl S, Krämer A, Steininger S, Sarioglu H, Leszczynski D, Nylund R, Hakanen A, Shiharshan A, Atkinson MJ, Tapio S. Low-dose irradiation causes rapid alterations to the proteome of the human endothelial cell line EA.hy926. Radiation and Environmental Biophysics **2011**; 50 (1): 155 – 166.

Pohjonen A. ^{137}Cs concentrations in summertime food plants of reindeer in Finnish reindeer management area. Master's Thesis. University of Jyväskylä, The Department of Biological and Environmental Science, Environmental Science and Technology, **2009**.

Prat O, Vercouter T, Ansoborlo E, Fichet P, Perret P, Kurttio P, Salonen L. Uranium speciation in drinking water from drilled wells in southern Finland and its potential links to health effects. Environmental Science & Technology **2009**; 43 (10): 3941 – 3946.

Prat O, Ansoborlo E, Sage N, Cavadore D, Lecoix J, Kurttio P, Quémeneur E. From cell to man: evaluation of osteopontin as a possible biomarker of uranium exposure. Environment International **2011**; 37: 657 – 662.

Prise KM, Schettino G, Vojnovic B, Belyakov O, Shao C. Microbeam studies of the bystander response. Journal of Radiation Research **2009**; 50 (Suppl. A): A1 – A6.

Puhakainen M, Heikkinen T. Tritium in the urine in Finnish people. Radiation Protection Dosimetry **2008**; 128 (2): 254 – 257.

Puhakainen M, Heikkinen T, Steinnes E, Thørring H, Outola I. Distribution of ^{90}Sr and ^{137}Cs in Arctic soil profiles polluted by heavy metals. Journal of Environmental Radioactivity **2005**; 81: 295 – 306.

Puhakainen M, Rahola T, Heikkinen T, Illukka E. Cs-134 and Cs-137 in lichen (Cladonia stellaris) in Southern Finland. Boreal Environmental Research **2007**; 12: 29 – 35.

Puranen L, Toivo T, Toivonen T, Pitkäaho R, Turunen A, Sihvonen A-P, Jokela K, Heikkinen P, Kumlin T, Juutilainen J. Space efficient system for whole-body exposure of unrestrained rats to 900 MZh electromagnetic fields. Bioelectromagnetics **2009**; 30: 120–128.

Purushothaman S, Peräjärvi K, Ranjan M, Saastamoinen A, Gloos K, Takahashi N, Dendooven P. Positive ion extraction across the superfluid-vapor helium interface. In: 25th International Conference on Low Temperature Physics (LT25). 2008 Aug 6–13; Amsterdam, The Netherlands. Journal of Physics: Conference Series **2009**; 150: 032086. (5 pp.)

Pöllänen R, Siiskonen T. Rapid identification of alpha-particle emitters from air samples using high-resolution alpha spectrometry. In: Strand P, Børretzen P, Jølle T (Eds.). Proceedings from the 2nd International Conference on Radioactivity in the Environment. 2–6 October 2005, Nice, France. Østerås, Norway: Norwegian Radiation Protection Authority; **2005**. p. 193–196.

Pöllänen R, Siiskonen T. High-resolution alpha spectrometry under field conditions – fast identification of alpha particle emitting radionuclides from air samples. Journal of Environmental Radioactivity **2006a**; 87: 279–288.

Pöllänen R, Siiskonen T. Minimum detectable activity concentration in direct alpha spectrometry from outdoor air samples: continuous monitoring versus separate sampling and counting. Health Physics **2006b**; 90: 167–175.

Pöllänen R, Siiskonen T. Direct alpha spectrometry from swipe samples. In: Proceedings of the 29th ESARDA Annual Meeting. 2007 May 22–24; Aix en Provence, France. [CD-ROM, **2007**]

Pöllänen R, Siiskonen T. Direct high-resolution alpha spectrometry for identifying transuranium elements in outdoor air. In: Proceedings of the International Conference on Monitoring, Assessments and Uncertainties for Nuclear and Radiological Emergency Response. 2005 Nov 21–25, Rio de Janeiro, Brazil. [CD-ROM, **2008a**]

Pöllänen R, Siiskonen T. Direct high-resolution alpha spectrometry from nuclear fuel particles in an outdoor air sample. Radiation Protection Dosimetry **2008b**; 124 (4): 454–463.

Pöllänen R, Siiskonen T, Vesterbacka P. High-resolution alphaspectrometry from thick sources. Radiation Measurements **2005**; 39: 565–568.

Pöllänen R, Ketterer ME, Lehto S, Hokkanen M, Ikäheimonen TK, Siiskonen T, Moring M, Rubio Montero MP, Martín Sánchez A. Multi-technique characterization of a nuclear bomb particle from the Palomares accident. Journal of Environmental Radioactivity **2006**; 90: 15–28.

Pöllänen R, Siiskonen T, Moring M, Juhanoja J. Direct alpha spectrometry for characterising hot particle properties. Radiation Measurements **2007**; 42: 1666–1673.

Pöllänen R, Karhunen T, Siiskonen T, Toivonen H, Pelikan A. Deconvolution of alpha spectra from hot particles. In: Oughton D, Kashparov V (Eds.). Radioactive Particles in the Environment. NATO Science for Peace and Security Series C: Environmental Security. Springer; **2009a**. p. 209–220.

Pöllänen R, Ruotsalainen K, Toivonen H. Determination of ^{239}Pu and ^{240}Pu isotope ratio for a nuclear bomb particle using X-ray spectrometry in conjunction with γ-ray spectrometry and non-destructive α-particle spectrometry. Nuclear Instruments and Methods in Physics Research A **2009b**; 610 (2): 515–521.

Pöllänen R, Toivonen H, Peräjärvi K, Karhunen T, Ilander T, Lehtinen J, Rintala K, Katajainen T, Niemelä J, Juusela M. Radiation surveillance using an unmanned aerial vehicle. Applied Radiation and Isotopes **2009c**; 67: 340–344.

Pöllänen R, Toivonen H, Peräjärvi K, Karhunen T, Smolander P, Ilander T, Rintala K, Katajainen T, Niemelä J, Juusela M, Palos T. Performance of an air sampler and a gamma-ray detector in a small unmanned aerial vehicle. Journal of Radioanalytical and Nuclear Chemistry **2009d**; 282: 433–437.

Pöllänen R, Toivonen T, Peräjärvi K, Karhunen T, Smolander P, Ilander T, Rintala K, Katajainen T, Niemelä J, Juusela M, Palos T. Sampling of airborne radionuclides and detection of ionizing radiation using an unmanned aerial vehicle. In: Maatela P, Korpela S (Eds.). Symposium Proceedings. NBC 2009. 7th Symposium on CBRNE threats. 8–11 June, 2009, Jyväskylä, Finland. Defence Forces Technical Research Centre, Publications 18. Helsinki: Defence Forces Technical Research Centre; **2009e**. p. 129–134.

Pöyry P, Komppa T, Kosunen A. A tandem calibration method for kerma-area product meters. In: Book of Extended Synopses. IAEA-CN-146. International Conference on Quality Assurance and New Techniques in Radiation Medicine. 2006 Nov 13–15; Vienna, Austria. **2006a**. p. 290–291.

Pöyry P, Komppa T, Kosunen A. X ray beam quality specification for kerma area product meters. In: Book of Extended Synopses. IAEA-CN-146. International Conference on Quality Assurance and New Techniques in Radiation Medicine. 2006 Nov 13–15; Vienna, Austria. **2006b**. p. 298–199.

Pöyry P, Zanca F, Bosmans H. Experimental investigation of the necessity for extra flat field corrections in quality control of digital mammography. International Workshop on Digital Mammography, 18–21 June 2006, Manchester, England. In: Astley S et al. (Eds.). IWDM 2006, LNCS 4046. Berlin Heidelberg: Springer-Verlag; **2006c**. p. 475–481.

Rahola T, Muikku M. Food-chain lichen-reindeer-man and body content of ^{137}Cs in Finnish reindeer herders from 1962 to 2002. In: Proceedings from the 6th International Conference on Environmental Radioactivity in the Arctic and Antarctic, 2–6 October **2005**, Nice, France. p. 92–95.

Rahola T, Saxén R, Puhakainen M. Artificial radioactivity in man and the environment. In: Proceedings of Symposium. 7th Russian-Finnish Symposium on Radiochemistry: "Modern problems of radiochemistry". 2005 Nov 16–18; Saint-Petersburg, Russia. St.Petersburg: VVM Co. Ltd; **2005**. p. 35–36.

Rahola T, Saxén R, Kostiainen E. Artificial radioactivity in human body and the environment. Radiochemistry **2006**: 626–631.

Rahola T, Muikku M, Etherington G, Hodgson A, Youngman M, Rojas-Palma C, van der Meer K, Liland A, Jaworska A, Jerstad A, Kruse P, del Rosario Pérez M, Zhanat Carr Z, Smagala G. Guidelines for triage and monitoring of people exposed to radiation after a malevolent act. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008a**. [CD-ROM, TS II.3.2: 3395 (8 pp.)]

Rahola T, Muikku M, Pellow PGD, Etherington G, Hodgson A, Youngman MJ, Challeton-de Vathaire C, Le Guen B, Bérard P, Lopez MA. A European network of experts with direct responsibility for monitoring and dosimetry after a deliberate release of radioactive material or a deliberate radiation exposure. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008b**. [CD-ROM, TS II.3.1: 3312 (8 pp.)]

Rahola T, Muikku M, Pellow PGD, Etherington G, Hodgson A, Youngman M J, Challeton-de Vathaire C, Le Guen B, Bérard P, Lopez MA. A European network of experts directly responsible for monitoring and assessment of doses after delibetare exposure to ionizing radiation. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008:13. Østerås: Norwegian Radiation Protection Authority; **2008c**. p. 168–174.

Rahola T, Muikku M, Rojas-Palma C, van der Meer K, Liland A, Jaworska A, Jerstad A, Kruse P, Etherington G, del Rosario Perez M, Carr Z, Smalaga G. Triage, monitoring and treatment of people after malevolent exposure to ionizing radiation – a handbook. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008:13. Østerås: Norwegian Radiation Protection Authority; **2008d**. p. 210–216.

Rahu M, Rahu K, Auvinen A, Tekkel M, Stengrevics A, Hakulinen T, Boice Jr JD, Inskip PD. Cancer risk among Chernobyl cleanup workers in Estonia and Latvia, 1986–1998: a cohort study. International Journal of Cancer **2006**; 119 (1): 162–268.

Ranebo Y, Pöllänen R, Eriksson M, Siiskonen T, Niagolova N. Characterization of radioactive particles using non-destructive alpha spectrometry. Applied Radiation and Isotopes **2010**; 68: 1754–1759.

Rantavaara A. Management options in the food chain for accidental radionuclide deposition. STUK-A215. Helsinki: Radiation and Nuclear Safety Authority; **2005**.

Rantavaara A. Ingestion doses in Finland due to ^{90}Sr, ^{134}Cs, and ^{137}Cs from nuclear weapons testing and the Chernobyl accident. Applied Radiation and Isotopes **2008**; 66: 1768–1774.

Rantavaara A, Aro LJ. Radiological impact of using forest tree biomass for energy and recycling the ash. Radioprotection **2009**; 44 (5): 927–932.

Rantavaara A, Karhula T, Puurunen M, Lampinen K, Taulavuori T. Costs and practicability of clean feeding of dairy cattle during radioactive contamination of grasslands. Journal of Environmental Radioactivity **2005a**; 83: 399–414.

Rantavaara A, Wallin H, Hasunen K, Härmälä K, Kulmala H, Latvio E, Liskola K, Mustonen I, Nieminen I, Tainio R. Finnish stakeholder engagement in the restoration of a radioactively contaminated food supply chain. Journal of Environmental Radioactivity **2005b**; 83: 305–317.

Read D, Black S, Buckby T, Hellmuth KH, Marcos N, Siitari-Kauppi M. Secondary uranium mineralization in southern Finland and its relationship to recent glacial events. Global & Planetary Change **2008**; 60 (3–4): 235–249.

Reisbacka H. Radon mitigation in large buildings in Finland. In: Valentin J, Cederlund T, Drake P, Finne IE, Glansholm A, Jaworska A, Paile W, Rahola T (Eds.). Radiological Protection in Transition – Proceedings of the XIV Regular Meeting of the Nordic Society for Radiation Protection, NSFS – Rättvik, Sweden, 27–31 August 2005. SSI Report 2005:15. Stockholm: Swedish Radiation Protection Authority; **2005**. p. 225–227.

Reisbacka H. Radon measurements in conventional Finnish workplaces during measurement seasons 2005–2007. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008:13. Østerås: Norwegian Radiation Protection Authority; **2008**. p. 130–134.

Reisbacka H. Radon measurement method with passive alpha track detector at STUK, Finland. In: Proceedings – Third European IRPA Congress, 14–18 June 2010, Helsinki, Finland. Helsinki: Nordic Society for Radiation Protection; **2011**. P03-15. p. 642–645.

Remondini D, Nylund R, Reivinen J, Poulletier de Gannes F, Veyret B, Lagroye I, Haro E, Angeles Trillo M, Capri M, Franceschi C, Schlatterer K, Gminski R, Fitzner R, Tauber R, Schuderer J, Kuster N, Leszczynski D, Bersani F, Maercker C. Gene expression changes in human cells after exposure to mobile phone microwaves. Proteomics **2006**; 6 (17): 4745–4754.

Repacholi MH, Lerchl A, Röösli M, Sienkiewicz Z, Auvinen A, Breckenkamp J, d'Inzeo G, Elliott P, Frei P, Heinrich S, Lagroye I, Lahkola, A, McCormick D, Thomas S, Vecchia P. Systematic review of wireless phone use and brain cancers & other head tumors. Bioelectromagnetics. **In Press**

Robinet JC, Sardini P, Delay F, Hellmuth KH. The effect of rock matrix heterogeneities near fracture walls on the residence time distribution (RTD) of solutes. Transport in Porous Media **2008**; 72: 393–408.

Rojas-Palma C, van der Meer K, Liland A, Jaworska A, Jerstad A, Kruse P, Smith K, Rahola T, Muikku M, Etherington G, del Rosario Pérez M, Carr Z, Smagala G. A handbook for the triage, monitoring and treatment of people exposed to a malevolent use of radiation. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008**. [CD-ROM, TS II.3.2: 1030 (7 pp.)]

Rojas-Palma C, Liland A, Jerstad AN, Etherington G, Pérez MR, Rahola T, Smith K (Eds.). TMT handbook: Triage, monitoring and treatment of people exposed to ionising radiation following a malevolent act. Østeras: Norwegian Radiation Protection Authority, **2009**.

Roos P, Outola I, Nygren U, Ramebäck H, Sidhu R. Assessment of wethering and leaching rates of Thule hot particles. NKS-215. Roskilde, Denmark: Nordic Nuclear Safety Research, **2010**.

Root T, Tattari S, Rantavaara A. Northern conditions influencing the selection of countermeasures after radioactive fallout in Finland. Journal of Environmental Radioactivity **2005**; 83: 359–370.

del Rosario Pérez M, Carr Z, Akashi M, Gent RN, Gourmelon P, Joussineau S, List V, Lloyd D, Valverde N, Wiley A, Rojas-Palma C, Kruse P, George Etherington G, Rahola T, Muikku M, Liland A, Jaworska A, Jerstad A, Smagala G. TMT Handbook: guidelines for treatment and long-term follow up of people exposed to radiation after a malevolent act. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008**. [CD-ROM, TS II.3.2: 464 (7 pp.)]

del Rosario Pérez M, Carr Z, Rojas-Palma C, van der Meer K, Smith K, Rahola T, Muikku M, Liland A, Jaworska A, Jerstad A. A new handbook on triage, monitoring and treatment of people following malevolent use of radiation. Health Physics **2010**; 98 (6): 898–902.

Röttger A, Honig A, Schmidt V, Buchröder H, Rox A, Butterweck G, Schuler Ch, Maringer FJ, Michielsen N, Howarth C, Miles JCH, Vargas A, Ortega X, Burian I, Turtiainen T, Jachs P, Edel-maier R, Hagberg N. Comparison of calibration facilities for radon activity concentration: Euromet Project 657. Metrologia **2005**; 42, Technical Supplement.

Röttger A, Honig A, Schmidt V, Buchröder H, Rox A, Butterweck G, Schuler Ch, Maringer FJ, Jachs P, Edelmaier R, Michielsen N, Howarth CB, Miles JCH, Vargas A, Ortega X, Burian I, Turtiainen T, Hagberg N. Radon activity concentration – a Euromet and BIPM supplementary comparison. Applied Radiation and Isotopes **2006**; 64: 1102–1107.

Salahel Din K, Vesterbacka P. Spatial distribution of U isotopes in sea-water sediments, Red Sea, Egypt. Journal of Environmental Radioactivity **2010**; 101: 165–169.

Salomaa S. Rapporteur's Summary 3: Contributed papers on biological effects and population and ecosystem studies. In: Protection of the environment from the effects of ionizing radiation. Proceedings of an international conference, Stockholm, 6–10 October 2003. Vienna: International Atomic Energy Agency; **2005**. p. 325–335.

Salomaa S. Non-targeted effects of ionising radiation – Implications for radiation protection. In: Proceedings of Full Papers. Second European IRPA Congress on Radiation Protection. 2006 May 15–19; Paris, France. Paris: Société Francaise de Radioprotection, International Radiation Protection Association; **2006**. p. 1–11. [CD-ROM]

Salomaa S, Ikäheimonen TK (Eds.). Research activities of STUK 2000–2004. STUK-A210. Helsinki: Radiation and Nuclear Safety Authority; **2005**.

Salomaa S, Sirkka L (Eds.). Research projects 2006–2008. STUK-A230. Helsinki: Radiation and Nuclear Safety Authority; **2008**. (In Finnish)

Salomaa S, Pinak M, Lazo T. Key note lecture. Science and values in radiological protection – Impact on radiological protection decision making. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008:13. Østerås: Norwegian Radiation Protection Authority; **2008a**. p. 21–28.

Salomaa S, Wright EG, Hildebrandt G, Kadhim M, Little MP, Prise KM, Belyakov O. Non-targeted effects of ionising radiation (NOTE) – European Integrated project, 2006–2010. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008b**. [CD-ROM, TS I.2.1: 2674 (10 pp.)]

Salomaa SI, Wright EG, Hildebrandt G, Kadhim MA, Little MP, Prise KM, Belyakov OV. Editorial – Non-DNA targeted effects. Mutation Research **2010**; 687: 1–2.

Salonen L. Alpha/beta liquid scintillation spectrometry in surveying Finnish groundwater samples. Pleiades Publishing, Inc., 2006. Published in Russian in Radiokhimiya 2006: 48 (6): 544–550. Published in English in Radiochemistry **2006a**; 48 (6): 606–612.

Salonen L. Alpha spillover depends on alpha energy: a new finding in alpha/beta liquid scintillation spectrometry. Proceedings in LSC 2005, Advances in Liquid Scintillation Spectrometry. Chalupnik S, Schönhofer F, Noakes J (Eds.) 2006 by the Arizona Board of Regents, University of Arizona; **2006b**. p. 135–148.

Salonen L. Interference from ^{210}Pb and its progenies in calibrating direct LSC method for ^{222}Rn in drinking water. In: Eikenberg J, Jäggi M, Beer H, Baehrle H (Eds.). LSC 2008. International conference on advances in liquid scintillation spectrometry. 2008 May 25–30; Davos, Switzerland. Switzerland: Paul Scherrer Institut; **2009a**. p. 109–117.

Salonen L. Performance of two-phase and homogenous sample composistions in measuring ^{222}Rn in drinking water. In: Eikenberg J, Jäggi M, Beer H, Baehrle H (Eds.). LSC 2008. International conference on advances in liquid scintillation spectrometry. 2008 May 25–30; Davos, Switzerland. Switzerland: Paul Scherrer Institut; **2009b**. p. 133–144.

Salonen L. Calibration of the direct LSC method for radon in drinking water: Interference from ^{210}Pb and its progenies accumulated in ^{226}Ra standard solution. Applied Radiation and Isotopes **2010a**; 68 (1): 131–138.

Salonen L. Comparison of two direct LS methods for measuring ^{222}Rn in drinking water using α/β liquid scintillation spectrometry. Applied Radiation and Isotopes **2010b**; 68: 1970–1979.

Sardini P, Robinet JC, Siitari-Kauppi M, Delay F, Hellmuth KH. Direct simulation of heterogeneous diffusion and inversion procedure applied to an out-diffusion experiment. Test case of Palmottu granite. Journal of Contaminant Hydrology **2007**; 93: 21–37.

Saxén RL. ^{90}Sr in Finnish freshwaters compared to ^{137}Cs. In: Strand P, Børretzen P, Jølle T (Eds.). Proceedings from the 2nd International Conference on Radioactivity in the Environment. 2–6 October 2005, Nice, France. Østerås, Norway: Norwegian Radiation Protection Authority; **2005**. p. 323–326.

Saxén R. Long-term behaviour of ^{137}Cs in Finnish lakes. In: Isotopes in Environmental Studies. Aquatic Forum 2004. Proceedings of an international conference held in Monaco, 25–29 October 2004. Conference & Symposium Papers 26/P. Vienna: International Atomic Energy Agency; **2006**. p. 229–232.

Saxén R. Application of the Eichrom-LSC method for determining ^{90}Sr in Finnish lake waters. In: Chalupnik S, Schönhofer F, Noakes J (Eds.). LSC 2005, Advances in Liquid Scintillation spectrometry. Proceedings of the 2500 International LiquidScintillation Conference, Katowice, Poland, **2007a**. p. 323–330.

Saxén R. ^{137}Cs in freshwater fish and lake water in Finland after the Chernobyl deposition. Boreal Environmental Research **2007b**; 12: 17–22.

Saxén R. ^{137}Cs in freshwater fish – environmental transfer an dose assessment. In: Book of extended synopsis, IAEA-CN-145. International Conference on Environmental Radioactivity, from measurements and assessments to regulation. 2007 Apr 23–27; Vienna, Austria. **2007c**. p. 347.

Saxén R, Hanste U-M. An Oxidizer/LSC method for the determination of ^{14}C in foodstuff samples. In: Eikenberg J, Jäggi M, Beer H, Baehrle H (Eds.). LSC 2008. International conference on advances in liquid scintillation spectrometry. 2008 May 25–30; Davos, Switzerland. Switzerland: Paul Scherrer Institut; **2009**. p. 279–285.

Saxén R, Ilus E. Transfer and behaviour of ^{137}Cs in two Finnish lakes and their catchments. Science of the Total Environment **2008**; 394 (2–3): 349–360.

Saxén R, Koskelainen U. ^{137}Cs in fishes and water in Finnish lakes – considerations for radiological risk assessment. Radioprotection **2005**; 40 Suppl 1: S649–S654.

Saxén R, Outola I. ^{137}Cs, ^{90}Sr and ^{3}H in freshwater environment and derived transfer factors for estimations in a radiation emergency situation. STUK-A241. Helsinki: Radiation and Nuclear Safety Authority; **2009**. (In Finnish)

Saxén R, Sundell J. ^{137}Cs in freshwater fish in Finland since 1986 – a statistical analysis with multivariate linear regression models. Journal of Environmental Radioactivity **2006**; 87 (1): 62–76.

Saxén R, Vives I Batlle J, Jones SR. Development of a concentration factor database for radionuclides in the aquatic environment: Applications and implications for FASSET. In: Protection of the environment from the effects of ionizing radiation. Contributed papers of an international conference, Stockholm, 6–10 October 2003. STI/PUB/1229 Companion CD. Vienna: International Atomic Energy Agency; **2005**. p. 151–154. [CD-ROM]

Saxén R, Rask M, Ruuhijärvi J, Vuorinen PJ, Rantavaara A, Koskelainen U. ^{137}Cs in small forest lakes of Finland after the Chernobyl accident. STUK-A236. Helsinki: Radiation and Nuclear Safety Authority; **2009**.

Saxén R, Heinävaara S, Rask M, Ruuhijärvi J, Rand H. Transfer of ^{137}Cs into fish in small forest lakes analysed with linear models. Journal of Environmental Radioactivity **2010**; 101: 647 – 653.

Schoemaker MJ, Swerdlow AJ, Ahlbom A, Auvinen A, Blaasaas KG, Cardis E, Collatz Christensen H, Feychting M, Hepworth SJ, Johansen C, Klæboe L, Lönn S, McKinney PA, Muir K, Raitanen J, Salminen T, Thomsen J, Tynes T. Mobile phone use and risk of acoustic neuroma: results of the Interphone case-control study in five North European countries. British Journal of Cancer **2005**; 93 (7): 842 – 848.

Schoemaker MJ, Swerdlow AJ, Auvinen A, Christensen HC, Feychting M, Johansen C, Klæboe L, Lönn S, Salminen T, Tynes T. Medical history, cigarette smoking and risk of acoustic neuroma: An international case-control study. International Journal of Cancer **2006**; 120 (1): 103 – 110.

Schoemaker M, Robertson L, Wigertz A, Jones M, Hosking F, Feychting M, Lönn S, McKinney P, Hepworth S, Muir K, Auvinen A, Salminen T, Kiuru A, Johansen C, Houlston R, Swerdlow A. Interaction between 5 genetic variants and allergy in glioma risk. American Journal of Epidemiology **2010**; 171 (11): 1165 – 1173.

Schüz J, Elliott P, Auvinen A, Kromhout H, Harbo Poulsen A, Johansen C, Olsen JH, Hillert L, Feychting M, Fremling K, Toledano M, Heinävaara S, Slottje P, Vermeulen R, Ahlbom A. An international prospective cohort study of mobile phone users and health (Cosmos): Design considerations and enrolment. Cancer Epidemiology **2011**; 35 (1): 37 – 43.

Schwartzbaum JA, Ahlbom A, Lönn S, Warholm M, Rannug A, Auvinen A, Christensen HC, Henriksson R, Johansen C, Lindholm C, Malmer B, Salminen T, Schoemaker MJ, Swerdlow AJ, Feychting M. An international case-control study of glutathione transferase and functionally related polymorphisms and risk of primary adult brain tumors. Cancer Epidemiology Biomarkers & Prevention **2007a**; 16 (3): 559 – 565.

Schwarzbaum JA, Ahlbom A, Lönn S, Malmer B, Wigertzx A, Auvinen A, Brookes AJ, Collatz, Christensen H, Henriksson R, Johansen C, Salminen T, Schoemaker MJ, Swerdlow AJ, Debinski W, Feychting M. An international case-control study of interleukin-4Ralpha, interleukin-13 and cyclooxygenase-2 genotypes and glioblastoma risk. Cancer Epidemiology Biomarkers & Prevention **2007b**; 16 (11): 2448 – 2454.

Seppänen J, Heinävaara S, Anttila A, Sarkeala T, Virkkunen H, Hakulinen T. Effects of different phases of an invitational screening program on breast cancer incidence. International Journal of Cancer **2006a**; 119: 920 – 924.

Seppänen J, Heinävaara S, Hakulinen T. Influence of alternative mammographic screening scenarios on breast cancer incidence predictions (Finland). Cancer Causes and Control **2006b**; 17: 1135 – 1144.

Seppänen J, Heinävaara S, Hakulinen T. Predicting impacts of mass-screening policy changes on breast cancer mortality. Statistics in Medicine **2008a**; 27: 5235–5251.

Seppänen J, Heinävaara S, Holli K, Hakulinen T. Comparison of cancer registry and clinical data as predictors for breast cancer survival. Cancer Causes Control **2008b**; 19:1299–1304.

Servomaa A, Holopainen M. Safety culture as development factor of radiation protection in medical use of radiation. Finnish Medical Journal **2005**; 22 (60): 2481–2484. (In Finnish)

Shaw G, Venter A, Avila R, Bergman R, Bulgakov A, Calmon P, Fesenko S, Frissel M, Goor F, Konoplev A, Linkov I, Mamikhin S, Moberg L, Orlov A, Rantavaara A, Spiridonov S, Thiry Y. Radionuclide migration in forest ecosystems – results of a model validation study. Journal of Environmental Radioactivity **2005**; 84: 285–296.

Sigurdson AJ, Ha M, Hauptmann M, Bhatti P, Sram RJ, Beskid O, Tawn EJ, Whitehouse CA, Lindholm C, Nakano M, Kodama Y, Nakamura N, Vorobtsova I, Oestreicher U, Stephan G, Yong LC, Bauchinger M, Schmid E, Chung HW, Darroudi F, Roy L, Voisin P, Barquinero JF, Livingston G, Blakey D, Hayata I, Zhang W, Wang C, Bennett LM, Littlefield LG, Edwards AA, Kleinerman RA, Tucker JD. International study of factors affecting human chromosome translocations. Mutation Research **2008**; 652: 112–121.

Siiskonen T. Dose from slow negative muons. Radiation Protection Dosimetry **2008**; 128 (2): 234–238.

Siiskonen T, Pöllänen R. Advanced simulation code for alpha spectrometry. Nuclear Instruments and Methods in Physics Research **2005**; A 550: 425–434

Siiskonen T, Pöllänen R. Alpha-electron and alpha-photon coincidences in high-resolution alpha spectrometry. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **2006**; 558 (2): 437–440.

Siiskonen T, Tapiovaara M. Weighting of secondary radiations in organ dose calculations. Radiation Protection Dosimetry **2010**; 141 (1): 18–26.

Siiskonen T, Toivonen H. A model for fitting peaks induced by fast neutrons in an HPGe detector. Nuclear Instuments and Methods in Physics Research **2005**; A 540: 403–411.

Siiskonen T, Tapiovaara M, Kosunen A, Lehtinen M, Vartiainen E. Monte Carlo simulations of occupational radiation doses in interventional radiology. The British Journal of Radiology **2007**; 80: 460–468.

Siiskonen T, Pöllänen R, Karhunen T. A versatile simulation code for alpha spectrometry: development of the graphical user interface and applications. Esarda Bulletin **2008a**; (40): 26–20.

Siiskonen T, Tapiovaara M, Kosunen A, Lehtinen M, Vartiainen E. Occupational radiation doses in interventional radiology: simulations. Radiation Protection Dosimetry **2008b**; 129: 36–38.

Siiskonen T, Huikari J, Haavisto T, Bergman J, Heselius S-J, Lill J-O, Lönnroth T, Peräjärvi K. Excitation functions of proton-induced reactions in ^{nat}Cu in the energy range 7–17 MeV. Applied Radiation and Isotopes **2009a**; 67 (11): 2037–2039.

Siiskonen T, Huikari J, Haavisto T, Bergman J, Heselius S-J, Lill J-O, Lönnroth T, Peräjärvi K, Vartti V-P. Excitation functions for proton-induced reactions on natural hafnium: Production of ^{177}Lu for medical use. Nuclear Instruments and Methods in Physics Research B **2009b**; B 267: 3500–3504.

Siiskonen T, Kettunen H, Peräjärvi K, Javanainen A, Rossi M, Trzaska WH, Turunen J, Virtanen A. Energy loss measurement of protons in liquid water. Physics in Medicine and Biology **2011**; 56 (8): 2367–2374.

Sinkko K, Ammann M, Hämäläinen RP, Mustajoki J. Facilitated workshop on clean-up actions in inhabited areas in Finland after an accidental release of radionuclides. STUK-A214. Helsinki: Radiation and Nuclear Safety Authority; **2005**.

Sinkko K, Ammann M, Hämäläinen RP, Mustajoki J. Facilitated workshop. A participatory method for planning of countermeasures in case of a nuclear Accident. STUK-A226. Helsinki: Radiation and Nuclear Safety Authority; **2008**.

Sipilä P, Järvinen H, Kosunen A, Ojala J, Niemelä J. Multipurpose, semi-anatomical water phantom for TPS verification. In: Book of Extended Synopses. IAEA-CN-182. International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS). **2010** Nov 9–12; Vienna, Austria. p. 459–460.

Skuterud L, Åhman B, Solatie D, Gaare E. Long-term decline of radiocaesium in Fennoscandian reindeer. NKS-193. Roskilde, Denmark: Nordic Nuclear Safety Research; **2009**.

Smans K, Tapiovaara M, Cannie M, Struelens L, Vanhavere F, Smet M, Bosmans H. Calculation of organ doses in x-ray examinations of premature babies. Medical Physics **2008a**; 35 (2): 556–568.

Smans K, Vaño E, Sanchez R, Schultz FW, Zoetelief J, Kiljunen T, Maccia C, Järvinen H, Bly R, Kosunen A, Faulkner K, Bosmans H. Results of a european survey on patient doses in paediatric radiology. Radiation Protection Dosimetry **2008b**; 129 (1–3): 204–210.

Smolander P, Kuukankorpi S, Moring M, Toivonen H. Real-time mobile measurement and analysis in a radiological emergency. In: Strand P, Børretzen P, Jølle T (Eds.). Proceedings from the 2nd International Conference on Radioactivity in the Environment. 2–6 October 2005, Nice, France. Østerås, Norway: Norwegian Radiation Protection Authority; **2005**. p. 388–391.

Smolander P, Kuukankorpi S, Moring M, Toivonen H. In-field management of spectrometric data in radiological threat and emergency. Journal of Radioanalytical and Nuclear Chemistry **2008**; 276 (2): 341–346.

Solatie D, Vesterbacka P, Muikku M, Rissanen K. ^{210}Po and ^{210}Pb in terrestrial subarctic food chain in Finland. In: Proceedings from the 6th International Conference on Environmental Radioactivity in the Arctic and Antarctic, 2–6 October **2005**, Nice, France. p. 108–112.

Solatie, D. Junttila, M. Vesterbacka, P. ^{210}Po and ^{210}Pb in the food chain lichen-reindeer-human. Radiochemistry **2006**; 48 (6): 632–633.

Solatie D, Leppänen A-P, Niskala P, Ylipieti J. ^{90}Sr and ^{137}Cs in deposition, grass and milk in Northern Finland. Radioprotection Supplement **2009**; 44 (5): 863–867.

Strålberg E, Berg K, Dowdall M, Eitrheim K, Klemola S, Nielsen SP, Pálsson SE, Ramebäck H, Rääf C, Roos P, Sickel M (Eds.). GammaSem Proceedings. A Nordic seminar for users of gamma spectrometry. Kjeller 28–29 September 2010. NKS-224. Roskilde, Denmark. Nordic Nuclear Safety Research; **2010**.

Sundell-Bergman S, Avila R, de la Cruz I, Zu S, Puhakainen M, Heikkinen T, Rahola T, Hosseini A, Nielsen S, Sigurgeirsson M. Assessing the impact of release of radionuclides into sewage systems in urban environment – simulation, modelling and experimental studies – LUCIA. NKS-192. Roskilde, Denmark: Nordic Nuclear Safety Research; **2009**.

Tapio S, Hornhardt S, Gomolka M, Leszczynski D, Posch A, Thalhammer S, Atkinson MJ. Use of proteomics in radiobiological research: current state of the art. Radiation and Environmental Biophysics **2010**; 49 (1): 1–4.

Tapiovaara M. Image quality measurements in radiology. Radiation Protection Dosimetry **2005**; 117 (1–3): 116–119.

Tapiovaara M. Relationships between physical measurements and user evaluation of image quality in medical radiology – a review. STUK-A219. Helsinki: Radiation and Nuclear Safety Authority; **2006**.

Tapiovaara MJ. Review of relationships between physical measurements and user evaluation of image quality. Radiation Protection Dosimetry **2008**; 129 (1–3): 244–248.

Tapiovaara M, Siiskonen T. PCXMC, A Monte Carlo program for calculating patient doses in medical x-ray examinations (2nd Ed.). STUK-A231. Helsinki: Radiation and Nuclear Safety Authority; **2008**.

Tenkanen-Rautakoski P. Number of radiological examinations in Finland in 2005. STUK-B-STO 62. Helsinki: Radiation and Nuclear Safety Authority; **2006**. (In Finnish)

Tenkanen-Rautakoski P (Ed.). Number of radiological examinations in Finland in 2008. STUK-B 121. Helsinki: Radiation and Nuclear Safety Authority; **2010**. (In Finnish)

Tenkanen-Rautakoski P, Järvinen H, Bly R. Estimation of the collective effective dose to the population from medical x-ray examinations in Finland. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. Buenos Aires: Sociedad Argentina de Radioprotección; **2008**. [CD-ROM, TS III.3.1: 690 (6 pp.)]

Tisnek N, Kalanxhi E, Serkland CW, Iversen J, Belyakov OV, Dahle J. A ^{238}Pu irradiator for exposure of cultured cells with alpha-radiation: construction, calibration and dosimetry. Applied Radiation and Isotopes **2009**; 67 (11): 1998–2002.

Toivonen H, Kuukankorpi, Moring M, Smolander P. Radionuclide source finding using a mobile laboratory for supporting counter terrorism actions. In: Maatela P, Pitkänen M (Eds.). NBC 2006 Symposium on Chemical, Biological, Nuclear and Radiological Threats – a Safety and Security Challenge. Tampere, Finland **2006**. p. 15–19.

Toivonen H, Ihantola S, Peräjärvi K, Pöllänen R, Ruotsalainen K, Turunen J. Position-sensitive αβγXe measurement techniques for non-destructive analysis of safeguard samples. In: Proceedings of Technical Meeting on Nuclear Spectrometry Methods for in-situ Characterization of Materials. **2008a** May 19–23; Vienna, Austria. [CD-ROM]

Toivonen H, Ihantola S, Peräjärvi K, Pöllänen R, Turunen J. Event-mode data acquisition for non-destructive laboratory analysis. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008:13. Østerås: Norwegian Radiation Protection Authority; **2008b**. p. 198–202.

Toivonen H, Vesterbacka K, Pelikan A, Mattila A, Karhunen T. $LaBr_3$ spectrometry for environmental monitoring. In: Proceedings. IRPA 12 – Strengthening Radiation Protection Worldwide. The 12th International Congress of the International Radiation Protection Association. 2008 Oct 19–24; Buenos Aires, Argentina. [Epub **2009**, TS I.1.1: 611 (10 pp.)]

Toivonen T. Microwave dosimetry in biological exposure studies and in practical safety evaluations. Academic dissertation. STUK-A243. Helsinki: Radiation and Nuclear Safety Authority; **2010**.

Toivonen T, Toivo T, Puranen L, Jokela K. Setup and dosimetry for exposure of human skin invivo to RF-EMFat 900MHz. Bioelectromagnetics **2008a**; 29 (3): 207–212.

Toivonen T, Toivo T, Pitkäaho R, Puranen L, Silfverhuth M, Mennander A, Hannula M, Hyttinen J, Jokela K. Setup and dosimetry for exposing anaesthetised pigs *in vivo* to 900 MHz GSM mobile phone fields. Bioelectromagnetics **2008b**: 29 (5): 363–370.

Toivonen T, Toivo T, Puranen L, Jokela K. Specific absorption rate and electric field measurements in the near field of six mobile phone base station antennas. Bioelectromagnetics **2009**; 30: 307–312.

Tokola K, Kurttio P, Salminen T, Auvinen A. Reducing overestimation in reported mobile phone use associated with epidemiological studies. Bioelectromagnetics **2008**; 29 (7): 559–563.

Toni MP, Aubineau-Lanièce I, Bovi M, Bordy J-M, Cardoso J, Chauvenet B, Gabris F, Grindborg J-J-E, Guerra AS, Kosunen A, Oliveira C, Pimpinella M, Sander T, Selbach H-J, Sochor V, Solc J, de PooterJ, van Dijk E. Traceability to absorbed-dose-to-water primary standards in dosimetry of brachytherapy sources used for radiotherapy. In: XIX IMEKO World Congress, Fundamental and applied metrology. **2009** Sep 6–11: Lisbon, Portugal.

Toroi P. Patient exposure monitoring and radiation qualities in two-dimensional digital x-ray imaging. Academic dissertation. STUK-A239. Helsinki: Radiation and Nuclear Safety Authority; **2009**.

Toroi P, Kosunen A. The energy dependence of the response of a patient dose calibrator. Physics in Medicine and Biology **2009**; 54: N151–N156.

Toroi P, Kosunen A. Calibration of kerma-area product meters with a patient dose calibrator. In: Book of Extended Synopses. IAEA-CN-182. International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS). **2010** Nov 9–12; Vienna, Austria. p. 167–168.

Toroi P, Zanca F, Young KC, van Ongeval C, Marchal G, Bosmans H. Experimental investigation on the choice of the tungsten/rhodium anode/filter combination for an amorphous selenium based digital mammography system. European Radiology **2007**; 17 (9): 2368–2375.

Toroi P, Komppa T, Kosunen A. A tandem calibration method for kerma-area product meters. Physics in Medicine and Biology **2008a**; 53: 4941–4958.

Toroi P, Komppa T, Kosunen A, Tapiovaara M. Effects of radiation quality on the calibration of kerma-area product meters in x-ray beams. Physics in Medicine and Biology **2008b**; 53: 5207–5221.

Toroi P, Komppa T, Kosunen A. Measurement of dose-area product. Calibration of DAP meters in x-ray beams. STUK-TR 4. Helsinki: Radiation and Nuclear Safety Authority; **2008c**. (In Finnish)

Toroi P, Nieminen MT, Tenkanen-Rautakoski P, Varjonen M. Determining air kerma from pixel values in digital mammography. Physics in Medicine and Biology **2009**; 54: 3865–3879.

Turtiainen T. Measurement of radon emanation of drainage layer media by liquid scintillation counting. Journal of Radioanalytical and Nuclear Chemistry **2009a**; 279 (1): 325–331.

Turtiainen T. Radon removal by aeration – observations on testing, installation and maintenance of domestic treatment units. Water Science and Technology: Water Supply-WSTWS **2009b**; 9 (4): 469–475.

Turtiainen T. Commentary to the paper Assessment of annual effective dose from natural radioactivity intake through wheat grain produced in Faisalabad, Pakistan. Journal of Radioanalytical and Nuclear Chemistry **2010**; 285: 409.

Turtiainen T, Salonen L. Prevention measures against radiation exposure to radon in well waters: analysis of the present situation in Finland. Journal of Water and Health **2010**; 8 (3): 500–512.

Turtiainen T, Weltner A. Assessment of dose during the life cycle of natural stone production. Radiation Protection Dosimetry **2007**; 124 (2):167–171.

Turtiainen T, Salahel-din K, Klemola S, Sihvonen A-P. Collective effective dose received by the population of Egypt from building materials. Journal of Radiological Protection **2008**; 28: 223–232.

Turtiainen T, Kostiainen E, Hallikainen A. ^{210}Pb and ^{210}Po in Finnish cereals. Journal of Environmental Radioactivity **2011**; 102 (5): 438–442.

Turunen J, Ihantola S, Peräjärvi K, Pöllänen R, Toivonen H. Novel spectrometric approach to non-destructive characterization of safeguards samples. ESARDA Bulletin 45, December **2010a**. p. 23–28.

Turunen J, Peräjärvi K, Pöllänen R, Toivonen H. PANDA – A novel instrument for non-destructive sample analysis. Nuclear Instruments and Methods in Physics Research A **2010b**; 613: 177–183.

Turunen J, Ihantola S, Peräjärvi K, Pöllänen R, Toivonen H, Hrnecek E. Collection and behaviour of radon progenies on thin Mylar foils. Radiation Measurements **2011**; 46 (6–7): 631–634.

Ungar K, Zhang W, Aarnio P, Ala-Heikkila J, Toivonen H, Siiskonen T, Isolankila A, Kuusi A, Moring M, Nikkinen M. Automation of analysis of airborne radionuclides observed in Canadian CTBT radiological monitoring networks using LINSSI. Journal of Radioanalytical and Nuclear Chemistry **2007**; 272 (2): 285–291.

Usoskin IG, Field CV, Schmidt GA, Leppänen A-P, Aldahan A, Kovaltsov GA, Possnert G, Ungar RK. Short term production and synoptic infuences on atmospheric ^{7}Be concentrations. Journal of Geophysical Research **2009**; 114: D06108. (11 pp.)

Vaaramaa K, Solatie D, Aro L, Lehto J. Concentrations of ^{210}Po and ^{210}Pb in soil and in wild berries in Finland. Natural Radiation Environment VIII Conference. **2007** Oct 7–12; Buzios, Brasilia.

Vaaramaa K, Solatie D, Aro L, Lehto J. ^{210}Po and ^{210}Pb in forest soil and in wild berries in Finland. In: Proceedings of the 8th International Symposium on the Natural Radiation Environment (NRE-VIII). 2007 Oct 7–12; Búzios, Brazil. New York: The American Institute of Physics (AIP); **2008**. p. 260–263.

Vaaramaa K, Solatie D, Aro L. Distribution of ^{210}Pb and ^{210}Po concentrations in wild berries and mushrooms in boreal forest ecosystems. Science of the Total Environment **2009**; 408: 84–91.

Vaaramaa K, Aro L, Solatie D, Lehto J. Distribution of ^{210}Pb and ^{210}Po in boreal forest soil. Science of the Total Environment **2010**; 408 (24): 6165–6171.

Valmari T, Kuuspalo K, Heikkinen M. Radon dose conversion factor in indoor air with a low-particle concentration. In: Proceedings of the 10th International Conference on Indoor Air Quality and Climate. 2005 Sep 4–9; Beijing, China. Tsinghua University Press; 2005. p. 2340–2341.

Valmari, T, Lehtimäki M, Taipale A. Filter clogging by bimodal aerosol. Aerosol Science & Technology **2006**; 40: 255–260.

Valmari T, Arvela H, Reisbacka H. Radon survey in Finnish day care centres. STUK-A221. Helsinki: Radiation and Nuclear Safety Authority; **2007**. (In Finnish)

Valmari T, Mäkeläinen I, Reisbacka H, Arvela H. House characteristics in the Finnish indoor radon data base. In: Barnet I, Neznal M, Petra Pacherova (Eds.).10th International Workshop on the Geological Aspects of Radon Risk Mapping. 2010 Sep 22–25; Prague, Czech Republic. Prague: Czech Geological Survey RADON v.o.s.; **2010a**. p. 223–231.

Valmari T, Mäkeläinen I, Reisbacka H, Arvela H. Radon Atlas of Finland 2010. STUK-A245. Helsinki: Radiation and Nuclear Safety Authority; **2010b**. (In Finnish, Swedish and English)

Valmari T, Mäkeläinen I, Arvela H, Reisbacka H. National measurement database in radon research in Finland. In: Proceedings – Third European IRPA Congress, 14–18 June 2010, Helsinki, Finland. Helsinki: Nordic Society for Radiation Protection; **2011a**. S03-05. p. 509–518.

Valmari T, Mäkeläinen I, Reisbacka H, Arvela H. Finnish radon situation analysed using national measurement database. Radiation Protection Dosimetry **2011b**. (In press.)

Vano E, Järvinen H, Kosunen A, Bly R, Malone J, Dowling A, Larkin A, Padovani R, Bosmans H, Dragusin O, Jaschke W, Torbica P, Back C, Schreiner A, Bokou C, Kottou S, Tsapaki V, Jankowski J, Papierz S, Domienik J, Werduch A, Nikodemova D, Salat D, Kepler K, Bor MD, Vassileva J, Borisova R, Pellet S, Corbett RH. Patient dose in interventional radiology: A European survey. Radiation Protection Dosimetry **2008**; 129 (1–3): 39–45.

Vartti V-P. Optimizing the counting conditions for Carbon-14 for the sample oxidizer-liquid scintillation counter method. In: Eikenberg J, Jäggi M, Beer H, Baehrle H (Eds.). LSC 2008. International conference on advances in liquid scintillation spectrometry. 2008 May 25–30; Davos, Switzerland. Switzerland: Paul Scherrer Institut; **2009**. p. 293–298.

Verschaeve L, Heikkinen P, verheyen G, Van Gorp U, Boonen F, Vander Plaetse F, Maes A, Kumlin T, Mäki-Paakkanen J, Puranen L, Juutilainen J. Investigation of co-genotoxic effects of radiofrequency electromagnetic fields in vivo. Radiation Research **2006**; 165: 598–607.

Vesterbacka P. ^{238}U–series radionuclides in Finnish groundwater-based drinking water and effective doses. Academic dissertation. STUK-A213. Helsinki: Radiation and Nuclear Safety Authority; **2005**.

Vesterbacka P. Natural radioactivity in drinking water in Finland. Boreal Environmental Research **2007**; 12: 11–16.

Vesterbacka P, Ikäheimonen TK. Optimization of ^{210}Pb determination via spontaneous deposition of ^{210}Pb on a silver disk. Analytica Chemica Acta **2005**; 545: 252–261.

Vesterbacka P, Pöllänen R. Simple method to determine ^{234}U and ^{238}U in water using alpha spectrometry. In: Proceedings – Third European IRPA Congress, 14–18 June 2010, Helsinki, Finland. Helsinki: Nordic Society for Radiation Protection; **2011**. P12-07. p. 1916–1921.

Vesterbacka P, Salonen L. Activity ratios between ^{238}U-series radionuclides in Finnish groundwater. In: Strand P, Børretzen P, Jølle T (Eds.). Proceedings from the 2nd International Conference on Radioactivity in the Environment. 2–6 October 2005, Nice, France. Østerås, Norway: Norwegian Radiation Protection Authority; **2005**. p. 124–127.

Vesterbacka P, Salonen L. A case study on removal of natural radionuclides from drinking water using conventional iron and manganese removal equipment. Vatten **2008a**; 64: 183–191.

Vesterbacka P, Salonen L. Pilot study of radionuclide removal. Using conventional iron- and manganese-removal equipment. Journal – American Water Works Association **2008b**; 100 (7): 24–29.

Vesterbacka P, Hämäläinen K, Lehto J. The effect of water treatment on the presence of particle-bound ^{210}Po and ^{210}Pb in groundwater. Radiochimica Acta **2005a**; 93:1–6.

Vesterbacka P, Mäkeläinen I, Arvela H. Natural radioactivity in drinking water in private wells in Finland. Radiation Protection Dosimetry **2005b**; 113: 223–232.

Vesterbacka P, Turtiainen T, Heinävaara S, Arvela H. Activity concentrations of ^{226}Ra and ^{228}Ra in drilled well water in Finland. Radiation Protection Dosimetry **2006**; 121 (4): 406–412.

Vesterbacka P, Turtiainen T, Hämäläinen K, Salonen L, Arvela H. Removal of radionuclides from household water. STUK-A225. Helsinki: Radiation and Nuclear Safety Authority; **2008**. (In Swedish)

Vesterbacka P, Klemola S, Salahel-Din K, Saman M. Comparison of analytical methods used to determine ^{235}U, ^{238}U and ^{210}Pb from sediment samples by alpha, beta and gamma spectrometry. Journal of Radioanalytical and Nuclear Chemistry **2009**; 281: 441–448.

Vesterbacka P, Pettersson H, Hanste U-M, Jakobson E, Kolstad T, Roos P, Östergren I. Intercomparison of Rn-222 determination from groundwater. Applied Radiation and Isotopes **2010**; 68: 214–218.

Vetikko V, Saxén R. Application of the ERICA Assessment Tool to freshwater biota in Finland. Journal of Environmental Radioactivity **2010**; 101: 82–87.

Vetikko V, Rantavaara A, Aro L, Plamboeck AH, Strålberg E (Eds.). NKS-B FOREST Seminar, Helsinki, 7–8 October 2008. Proceedings. NKS-189. Roskilde, Denmark: Nordic Nuclear Safety Research; **2009**.

Vetikko V, Rantavaara A, Moilanen M. Uptake of ^{137}Cs by berries, mushrooms and needles of Scots pine in peatland forests after wood ash application. Journal of Environmental Radioactivity **2010**; 101: 1055–1060.

Virtanen A, Pukkala E, Auvinen A. Incidence of bone and soft tissue sarcomas after radiotherapy: A cohort study of 295,712 Finnish cancer patients. International Journal of Cancer **2006**; 118 (4): 1017 – 1021.

Virtanen A, Pukkala E, Auvinen A. Angiosarcoma after radiotherapy: a cohort study of 332, 163 Finnish cancer patients. British Journal of Cancer **2007**; 97 (1): 115 – 117.

Vrijheid M, Cardis E, Armstrong BK, Auvinen A, Berg G, Blaasaas KG, Brown J, Carroll M, Chetrit A, Christensen HC, Deltour I, Feychting M, Giles GG, Hepworth SJ, Hours M, Iavarone I, Johansen C, Klæboe L, Kurttio P, Lagorio S, Lönn S, McKinney PA, Montestrucq L, Parslow RC, Richardson L, Sadetzki S, Salminen T, Schüz J, Tynes T, Woodward A. Validation of short term recall of mobile phone use for the Interphone study. Occupational and Environmental Medicine **2006**; 63: 237 – 243.

Vrijheid M, Cardis E, Ashmore P, Auvinen A, Bae J-M, Engels H, Gilbert E, Gulis G, Habib RR, Howe G, Kurtinaitis J, Malker H, Muirhead CR, Richardson DB, Rodriguez-Artalejo, Rogel A, Schubauer-Berigan M, Tardy H, Telle-Lamberton M, Usel M, Veress K. Mortality from diseases other than cancer following low doses of ionizing radiation: results from the 15-Country Study of nuclear industry workers. International Journal of Epidemiology **2007a**; 36: 1126 – 1135.

Vrijheid M, Cardis E, Blettner M, Gilbert E, Hakama M, Hill C, Howe G, Kaldor J, Muirhead CR, Schubauer-Berigan M, Yoshimura T, Ahn Y-O, Ashmore P, Auvinen A, Bae J-M, Engels H, Gulis G, Habib RR, Hosoda Y, Kurtinaitis J, Malker H, Moser M, Rodriguez-Artalejo F, Rogel A, Tardy H, Telle-Lamberton Turai I, Usel M, Veress K. The 15-country collaborative study of cancer risk among radiation workers in the nuclear industry: Design, epidemiological methods and descriptive results. Radiation Research **2007b**; 167: 361 – 379.

Vrijheid M, Cardis E, Ashmore P, Auvinen A, Gilbert E, Habib R, Malker H, Colin R, Muirhead C, Richardson DB, Rogel A, Schubauer-Berigan M, Tardy H, Telle-Lamberton M. Ionizing radioation and risk of chronic lymphocytic leukemia in the 15-country study of nuclear industry workers. Short Communication. Radiation Research **2008**; 170:661 – 665.

Vrijheid M, Mann S, Vecchia P, Wiart J, Taki M, Ardoino L, Armstrong BK, Auvinen A, Bédard D, Berg-Beckhoff G, Brown J, Chetrit A, Collatz-Christensen H, Combalot E, Cook A, Deltour I, Feychting M, Giles GG, Hepworth SJ, Hours M, Iavarone I, Johansen C, Krewski D, Kurttio P, Lagorio S, Lönn S, McBride M, Montestruq L, Parslow RC, Sadietzki S, Schüz J, Tynes T, Woodward A, Cardis E. Determinants of mobile phone output power in a multinational study – implications for exposure assessment. Occupational and Environmental Medicine, **2009a**: 66: 664 – 671

Vrijheid M, Richardson L, Bruce K, Armstrong BK, Auvinen A, Berg G, Carroll M, Chetrit A, Deltour I, Feychting M, Giles G, Hours M, Iavarone I, Lagorio S, Lönn S, Mcbride M, Parent ME, Sadetzki S, Salminen T, Sanchez M, Schlehofer B, Schüz J, Siemiatycki J, Tynes T, Woodward A, Yamaguchi N, Cardis E. Quantifying the impact of selection bias caused by nonparticipation in a case-control study of mobile phone use. Annals of Epidemiology **2009b**; 19 (1): 33 – 41.

Vähävihu K, Ylianttila L, Salmelin R, Lamberg-Allardt C, Viljakainen H, Tuohimaa P, Reunala T, Snellman E. Heliotherapy improves vitamin D balance and atopic dermatitis. The British Journal of Dermatology **2008**: 158 (6): 1323–1328.

Vähävihu K, Ylianttila L, Kautiainen H, Lamberg-Allardt C, Hasan T, Tuohima P, Reunala T, Snellman E. Narrowband ultraviolet B course improves vitamin D balance in women in winter. British Journal of Dermatology **2010a**; 162 (4): 848–853.

Vähävihu K, Ylianttila L, Kautiainen H, Tuohimaa P, Reunala T, Snellman E. Spore film dosimeters are feasible for UV dose monitoring during heliotherapy. Photochemistry and Photobiology **2010b**; 86 (5): 1174–1178.

Whitehouse CA, Edwards AA, Tawn EJ, Stephan G, Oestreicher U, Moquet JE, Lloyd DC, Roy L, Voisin P, Lindholm C, Barquinero J, Barrios L, Caballin MR, Darroudi F, Fomina J. Translocation yields in peripheral blood lymphocytes from control populations. International Journal of Radiation Biology **2005**; 81 (2): 139–145.

Wigertz A, Lönn S, Schwartzbaum J, Hall P, Auvinen A, Johansen C, Klaeboe L, Salminen T, Schoemaker MJ, Swerdlow AJ, Tynes T, Feychting M. Allergic conditions and brain tumor risk. American Journal of Epidemiology **2007**; 166: 941–950.

Wigertz A, Lönn S, Hall P, Auvinen A, Christensen HC, Johansen C, Klaeboe L, Salminen T, Schoemaker M, Swerdlow AJ, Tynes T, Feychting M. Reproductive factors and risk of meningioma and glioma. Cancer Epidemiology, Biomarkers & Prevention **2008**; 17 (10): 2663–2670.

Ylianttila L, Schreder J. Temperature effects of PTFE diffusers. Optical Materials **2005**; 32: 1811–1814.

Ylianttila L, Visuri R, Huurto L, Jokela K. Evaluation of a single-monochromator diode array spectroradiometer for sunbed UV-radiation measurements. Photochemistry and Photobiology **2005**; 81: 333–341.

Ylipieti J, Solatie D. Changes in ^{137}Cs activity concentrations with time in various fish species and water in lakes of Finnish Lapland. In: Nordic Society for Radiation Protection – NSFS. Proceedings of the NSFS XV conference in Ålesund Norway, 26–30 of May 2008. StrålevernRapport 2008: 13. Østerås: Norwegian Radiation Protection Authority; **2008**. p. 141–145.

Ylipieti J, Rissanen K, Kostiainen E, Salminen R, Tomilina O, Täht K, Gilucis A, Gregorauskiene V. Chernobyl fallout in the uppermost (0–3cm) humus layer of forest soil in Finland, North East Russia and Baltic countries in 2000–2003. Science of the Total Environment **2008**; 407: 315–323.

Zanca F, Jacobs J, Pöyry P, Van Ongeval C, Carton, AC, Deprez T, Marchal G, Bosmans H. Development and implementation of a user friendly and automated environment for creation of databases of digital mammograms with simulated microcalcifications. In: Jiang Y, Eckstein MP (Eds.). Image perception, observer performance, and technology assessment. Proceedings of SPIE (The International Society for Optical Engineering), 17 March 2006. Medical Imaging **2006**.

Zanca F, Van Ongeval C, Jacobs J, Pöyry P, Marchal G, Bosmans H. Evaluation of the global effect of anatomical background on microcalcifications detection. In: Jiang Y, Sahiner B (Eds.). Medical Imaging 2007: Image perception, observer performance and technology assessment. Proceedings of SPIE, Volume 6515, 5 March **2007**.

Zeeb H, Shannoun F (Eds.). WHO radon handbook on indoor radon: A public healt perspective. New York: World Health Organization; **2009**.

Zhang W, Yi J, Mekarski P, Hoffman I, Ungar K, Leppänen A-P. A system for low-level the cosmogenic ^{22}Na radionuclide measurement by gamma-gamma coincidence method using BGO detectors. Journal of Radioanalytical and Nuclear Chemistry **2011**; 287 (2): 551–555.]

Zinger I, Copplestone D, Brown J, Sjöblom K-L, Hänninen R, Jones S, Pröhl G, Oughton D, Jacqueline Garnier-Laplace J, Gómez-Ros J-M. Zinger I (Eds.). Deliverable D 8: Considerations for applying the ERICA Integrated Approach. European Commission; **2007a**.

Zinger I, Vetikko V, Sjöblom K-L, Jones S, Hubbard L, Copplestone D, Michalik B, Prlic I, Momal P. Deliverable D7g: Summary of the EUG event on: management, compliance and demonstration. European Commission; **2007b**.

Zvonova I, Krajewski P, Berkovsky V, Ammann M, Duffa C, Filistovic V, Homma T, Kanyar B, Nedveckaite T, Simon SL, Vlasov O, Webbe-Wood D. Validation of ^{131}I ecological transfer models and thyroid dose assessments using Chernobyl fallout data from the Plavsk district, Russia. Journal of Environmental Radioactivity **2010**; 101: 8–15.

STUK-A-reports

STUK-A248 Salomaa S, Sulonen N (Eds.). Research activities of STUK 2005–2010. Helsinki 2011.

STUK-A247 Larjavaara S. Occurrence studies of intracranial tumours. Doctoral thesis. Helsinki 2011.

STUK-A246 Lahkola A. Mobile phone use and risk of brain tumours. Doctoral thesis. Helsinki 2010.

STUK-A245 Valmari T, Mäkeläinen I, Reisbacka H, Arvela H. Suomen radonkartasto 2010 – Radonatlas över Finland 2010 – Radon Atlas of Finland 2010. Helsinki 2010.

STUK-A244 Arvela H, Mäkeläinen I, Holmgren O, Reisbacka H. Radon uudisrakentamisessa – Otantatutkimus 2009. Helsinki 2010.

STUK-A243 Toivonen T. Microwave dosimetry in biological exposure studies and in practical safety evaluations. Doctoral thesis. Helsinki 2010.

STUK-A242 Mäkeläinen I, Kinnunen T, Reisbacka H, Valmari T, Arvela H. Radon suomalaisissa asunnoissa – Otantatutkimus 2006. Helsinki 2009.

STUK-A241 Saxén R, Outola I. Vesistöjen ja juomaveden ^{137}Cs, ^{90}Sr ja ^{3}H sekä pitoisuuksien arviointi valmiustilanteessa. Helsinki 2009.

STUK-A240 Kostiainen E, Ylipieti J. Radioaktiivinen cesium Suomen ruokasienissä. Helsinki 2009.

STUK-A239 Toroi P. Patient exposure monitoring and radiation qualities in two-dimensional digital x-ray imaging. Doctoral thesis. Helsinki 2009.

STUK-A238 Ilus E. Environmental effects of thermal and radioactive discharges from nuclear power plants in the boreal brackish-water conditions of the northern Baltic Sea. Doctoral thesis. Helsinki 2009.

STUK-A237 Arvela H, Reisbacka H. Radonsanering av bostäder. Helsinki 2009.

STUK-A236 Saxén R, Rask M, Ruuhijärvi J, Vuorinen P, Rantavaara A, Koskelainen U. ^{137}Cs in small forest lakes of Finland after the Chernobyl accident. Helsinki 2009.

STUK-A235 Mustonen R, Sjöblom K-L, Bly R, Havukainen R, Ikäheimonen T. K, Kosunen A, Markkanen M, Paile W. Säteilysuojelun perussuositukset 2007. Suomenkielinen lyhennelmä julkaisusta ICRP-103. Helsinki 2009.

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